Physically active academic lessons

de Greeff, Johannes Wilhelmus

Dissertation

Physically active academic lessons:
Effects on physical fitness and executive functions in primary school children

J.W. (Marck) de Greeff

University of Groningen / University Medical Center Groningen
Center for Human Movement Sciences
June 2016

The studies described in this thesis have been conducted at the Center for Human Movement Sciences. This center is part of the University Medical Center Groningen and the University of Groningen, the Netherlands.

This study was financially supported by an Onderwijs Bewijs Grant from the Ministry of Education, Culture and Science (ODB10015).

PhD training was facilitated by the research school of Behavioral and Cognitive Neuroscience (BCN) and the Research Institute Science in Healthy Ageing and healthcaRE (SHARE), both part of the Graduate school for Medical Sciences.

Printing of this thesis was financially supported by:
• University Medical Center Groningen
• University of Groningen
• Graduate School of Medical Sciences

rijksuniversiteit groningen

umcg

ISBN
978-90-367-9309-4 (printed version)
978-90-367-9308-7 (electronic version)

Cover & Lay-out design
www.proefschriftopmaak.nl, Groningen

Print
Netzodruk Groningen

Physically active academic lessons:
effects on physical fitness and executive functions in primary school children

Proefschrift

ter verkrijging van de graad van doctor aan de
Rijksuniversiteit Groningen
op gezag van de
rector magnificus prof. dr. E. Sterken
en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op

woensdag 30 november 2016 om 12.45 uur

door

Johannes Wilhelmus de Greeff

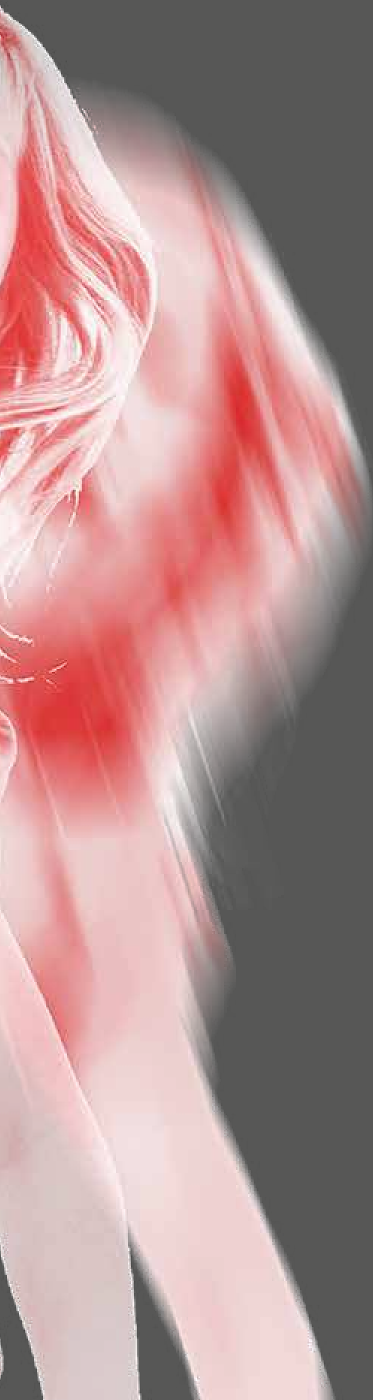
geboren op 3 april 1986
te Voorst

Promotores
Prof. dr. C. Visscher
Prof. dr. R.J. Bosker

Copromotores
Dr. E. Hartman
Dr. S. Doolaard

Beoordelingscommissie
Prof. dr. R. Nijhuis-Van der Sanden
Prof. dr. W. van Mechelen
Prof. dr. L.H.V. van der Woude

TABLE OF CONTENTS



CHAPTER 1

General introduction

A recent study has shown that within the period of 2000 and 2014 the number of Dutch preadolescent children (6-12 years) that achieve the recommended amount of moderate-to-vigorous physical activity (MVPA) is declining, while the time spent in physical inactivity is increasing (Hildebrandt et al., 2015). Physical activity is generally defined as *"any bodily movement produced by skeletal muscles that results in energy expenditure"* (Caspersen et al., 1985, p. 126). The current international physical activity guidelines for youth suggest that all preadolescent children should accumulate 60 minutes of daily MVPA, which refers to activity that is performed at 3.0 or more times the intensity of rest (WHO, 2010). This trend of increased time spend in physical inactivity has been reported in other countries as well (WHO, 2010). Because a physical inactive lifestyle tracks into adulthood (Twisk et al., 2000), it is important to implement and evaluate effective strategies for increasing physical activity in preadolescent children.

It is already known that children that participate in MVPA regularly, improve their physical fitness (Kriemler et al., 2010; Kristensen et al., 2010) and lower their health risk (e.g. obesity and hypertension) (Janssen & LeBlanc, 2010). Physical fitness, considered as a set of subdomains that contribute to the ability to perform physical activity and exercise (Caspersen et al., 1985), is for a large part determined by the physical activity pattern over a recent period (weeks or months). In the current thesis, we have focused on the health-related subdomains of physical fitness: cardiovascular fitness, which is the capacity of the cardiovascular and respiratory system to perform prolonged strenuous exercise; muscular fitness, defined as the capacity of the muscles to perform work against a resistance; and body composition, defined as the relative amount of muscle, fat, bone and other vital parts of the body (Caspersen, 1985).

Lately, there is an increasing scientific interest in the hypothesis that regular MVPA might not only lower childhood health problems (e.g. obesity and hypertension), but might also promote improvements in cognitive functions. This hypothesis is partly supported by an abundant number of cross-sectional studies that demonstrated that improvements in physical fitness is related with improvements in cognitive functions (see Hillman et al., 2011; Tomporowski et al., 2011 for reviews). Interestingly, these cognitive benefits from physical fitness are suggested to be selective or disproportionately larger for executive functions compared with other cognitive functions (Etnier et al., 2006). Executive functions, which are effortful cognitive processes that are necessary for goal directed cognition and behavior (Welsh et al., 2006), have a crucial role in mental health and are closely related with academic performance (Gathercole et al., 2004; St Clair-Thompson & Gathercole, 2006). Executive functions consist of at least three related domains: inhibition, which is the ability to avoid dominant or automatic responses and suppress environmental interference; working memory, which involves temporarily keeping relevant information and further processing this information; and cognitive flexibility, which requires children to switch between multiple tasks (Diamond, 2013; Miyake et al., 2000).

Typical classroom behavior of preadolescent children is mainly sedentary, with current curriculums contributing to around 7-8 hours a day spent in sedentary behavior (Esliger & Hall, 2009). Physical exercise programs that focus on increasing the time spent in MVPA and reducing physical inactivity during the school curriculum usually come with the loss of academic instruction time. Given the competing curriculum demands and the high pressure on improving academic performance (Erwin et al., 2012), implementing a physical exercise program is therefore difficult to realize. Coupling physical and cognitive demands might be an important alternative strategy to enhance physical fitness, executive functions and academic performance. Physically active academic lessons are an innovative strategy that introduces MVPA in the classroom, that do not detract from children's learning and come with the possible cognitive benefits from MVPA (Donnelly & Lambourne, 2011). We therefore designed and implemented an intervention program in which Dutch children are physically active during the regular mathematic and language lessons. Possible benefits of these physically active academic lessons could especially be of importance in children with a low socioeconomic status (SES). A child's SES is a construct that is often conceptualized as the social standing or class of the child's parents or caregivers (Hauser, 1994). The Dutch classification of social disadvantage (a dichotomous variable) is used as a measure of SES in the current thesis. Preadolescent children of which their parents completed less than three years of secondary education are in the Netherlands classified as children with a social disadvantage (SDC) (Ministry of Education, Culture and Science, 2006). It is well-documented that SDC are at risk for a low physical fitness (Duncan et al., 1994; Poulton et al., 2002) and generally score lower on academic performance (Chomitz et al., 2008; Sirin, 2005) compared with children without this social disadvantage (non-SDC) (Chomitz et al., 2008). This so called achievement gap continues through adolescence and adulthood, with large economic and social consequences for the career of SDC during adolescence and adulthood (Bradley & Corwyn, 2002). The first aim of the current thesis was therefore to investigate the relationships between physical fitness, executive functions and academic performance in SDC and non-SDC. Secondly, we investigated the effects of physically active academic lessons on physical fitness and executive functions[1].

[1]This thesis is closely related to another thesis that focuses on the implementation and effects of physically active academic lessons on academic performance (Mullender-Wijnsma, in progress).

THEORETICAL FRAMEWORK

Possible mechanisms underlying the effects of MVPA on cognition

The hypothesized model illustrated in Figure 1.1 provides an overview of the possible effects of regular MVPA on cognition in preadolescent children. Firstly, the model assumes that because of the physically active academic lessons are implemented during a time in which the children normally are required to sit still, the amount of in-school MPVA increases. According to the cardiovascular fitness hypothesis, regular MVPA increases physical fitness, which in turn leads to several structural changes in the brain (Etnier et al., 1997). Although it is originally stated that this applies for cardiovascular fitness, gains in muscular fitness might also lead to structural changes in the brain. It has been shown that muscular fitness training in adults increases concentration levels of neurotransmitters such as the insulin-like growth factor I, which promotes neuronal growth (Liu-Ambrose & Donaldson, 2009). The executive functions hypothesis, originally based on results from adult studies, states that MVPA leads to increased activity in selective parts of the brain structural network and especially improves executive functions (Colcombe & Kramer, 2003). Support for this hypothesis can also be found in studies that focus on preadolescent children. For example, MRI studies with preadolescent children have shown that physical fitness is related with increased volumes of specific regions of the basal ganglia (Chaddock, Erickson, Prakash, VanPatter et al., 2010) and hippocampus (Chaddock, Erickson, Prakash, Kim et al., 2010). There is also growing evidence that even a single bout of MVPA (also referred to as acute MVPA) can cause physiological and neurological responses, such as an improved blood flow in the brain and an enhancement of

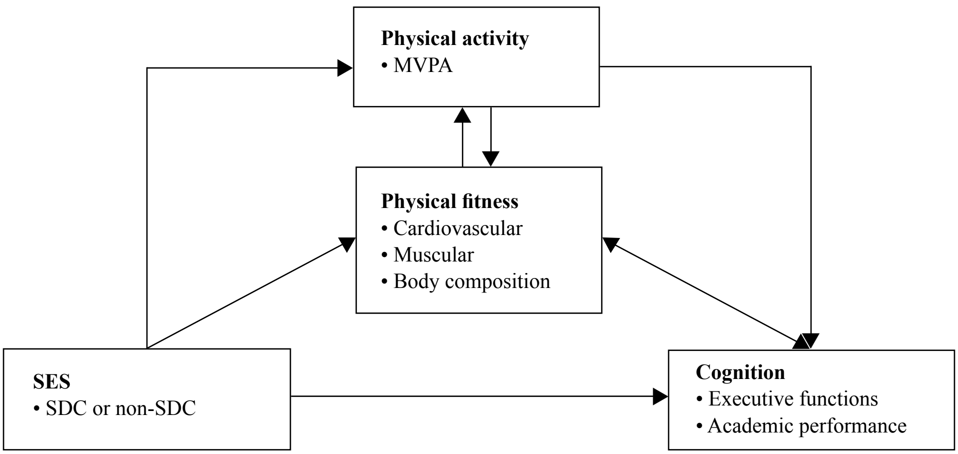


Figure 1.1 Hypothesized model underlying the effects of physical activity on the relation between SES and cognition.
SES: socioeconomic status; SDC: socially disadvantaged children; non-SDC: children without a social disadvantage; MVPA: moderate-to-vigorous physical activity.

the concentration of various neurotransmitters involved in cognitive processes. An example of a neurotransmitter that is positively affected by MVPA is the brain-derived neurotrophic factor (BDNF), of which stimulating neurogenesis and synaptic restauration are one of its roles (Dishman et al., 2006; Winter et al., 2007). Although the effects of these responses typically disappear after a short period (Curlik & Shors, 2013), regularly challenging the brain with physically active academic lessons might, in the long term, result in more structural changes in the brain structural network (Moreau, 2015).

Secondly, the model in Figure 1.1 assumes that there are considerable differences between SDC and non-SDC on cognition that should be taken into account when investigating the effects of physically active academic lessons. For example, if SDC score lower on physical fitness, it is more likely that they will improve on physical fitness, while non-SDC would need a longer period and/or higher intensity in order to improve their physical fitness.

AIMS AND OUTLINE OF THIS THESIS

The main aim of the research described in the current thesis is to study the effects of physically active academic lessons on physical fitness and executive functions in primary school children. We started this research by first investigating the relationships between physical fitness, executive functions and academic performance. These relationships are examined in SDC and non-SDC. Secondly, we investigated the effects of physically active academic lessons on physical fitness and executive functions.

The aim of Chapter 2 is to examine the relationships between physical fitness and academic performance. This chapter gives insight into the differences between SDC and non-SDC on physical fitness and academic performance. In addition, as both physical fitness (cardiovascular fitness and muscular fitness) and academic performance (mathematics, spelling and reading) can be divided in different subdomains, this chapter gives in particular insight into the associations between each subdomain of physical fitness and academic performance. Finally, the chapter examines whether physical fitness is a mediator between SES and academic performance.

In Chapter 3 the relationships between social disadvantage, physical fitness and executive functions are examined. The differences between SDC and non-SDC on executive functions are studied. In addition, it is investigated whether physical fitness indirectly influences the relationship between social disadvantage and executive functions. It was hypothesized that SDC score lower on executive functions compared with non-SDC and that physical fitness was related with executive functions in both SDC and non-SDC. Secondly, it was hypothesized that a lower performance of SDC on executive functions can be partly explained by a lower performance on physical fitness.

Chapter 4 describes the effect of physically active academic lessons on body mass index (BMI) and physical fitness. In a cluster-randomized controlled trial (cluster-RCT), children from twelve primary schools followed a 22-week intervention program in which physical activity was integrated in the mathematics and language lessons. The program was provided three times a week during school time. The control group followed the regular curriculum. The posttest scores on BMI and physical fitness of the intervention group was compared with the scores of the control group, after controlling for pretest differences. The hypothesis was that being physically active during these lessons would decrease BMI and increase physical fitness.

Chapter 5 examined the effects of physically active academic lessons on physical fitness and executive functions after two years. The children that followed the 22-week intervention program in the first year of the cluster-RCT, continued following the physically active academic lessons in the next school year (for a period of another 22 weeks). Baseline and posttest scores after one and after two years of the intervention group are compared with the control group. Finally, in Chapter 6 a summary is provided of the most important findings of the research described in the current thesis. Following this summary, the conclusions, limitations and suggestions for future research are discussed.

REFERENCES

Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Review of Psychology, 53*(1), 371-399.

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports, 100*(2), 126-131.

Chaddock, L., Erickson, K. I., Prakash, R. S., Kim, J. S., Voss, M. W., VanPatter, M., et al. (2010). A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. *Brain Research, 1358*, 172-183.

Chaddock, L., Erickson, K. I., Prakash, R. S., VanPatter, M., Voss, M. W., Pontifex, M. B., et al. (2010). Basal ganglia volume is associated with aerobic fitness in preadolescent children. *Developmental Neuroscience, 32*(3), 249-256.

Chomitz, V. R., Slining, M. M., McGowan, R. J., Mitchell, S. E., Dawson, G. F., & Hacker, K. A. (2008). Is there a relationship between physical fitness and academic achievement? Positive results from public school children in the northeastern United States. *Journal of School Health, 79*(1), 30-37.

Colcombe, S. J., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science, 14*(2), 125-130.

Curlik, D., & Shors, T. (2013). Training your brain: Do mental and physical (MAP) training enhance cognition through the process of neurogenesis in the hippocampus? *Neuropharmacology, 64*(1), 506-514.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135-168.

Dishman, R. K., Berthoud, H., Booth, F. W., Cotman, C. W., Edgerton, V. R., Fleshner, M. R., et al. (2006). Neurobiology of exercise. *Obesity, 14*(3), 345-356.

Donnelly, J. E., & Lambourne, K. (2011). Classroom-based physical activity, cognition, and academic achievement. *Preventive Medicine, 52*, S36-S42.

Duncan, G. J., Brooks-Gunn, J., & Klebanov, P. K. (1994). Economic deprivation and early childhood development. *Child Development, 65*(2), 296-318.

Erwin, H., Fedewa, A., Beighle, A., & Ahn, S. (2012). A quantitative review of physical activity, health, and learning outcomes associated with classroom-based physical activity interventions. *Journal of Applied School Psychology, 28*(1), 14-36.

Esliger, D., & Hall, J. (2009). Accelerometry in children. In R. Craig, J. Mindell & V. Hirani (Eds.), *Physical activity and fitness* (1st ed., pp. 159-180). Leeds: The NHS Information Centre for health and social care.

Etnier, J. L., Nowell, P. M., Landers, D. M., & Sibley, B. A. (2006). A meta-regression to examine the relation ship between aerobic fitness and cognitive performance. *Brain Research Reviews, 52*(1), 119-130.

Etnier, J. L., Salazar, W., Landers, D. M., Petruzzello, S. J., Han, M., & Nowell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: A meta-analysis. *Journal of Sport & Exercise Psychology, 19,* 249-277.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology, 40*(2), 177-190.

Hauser, R. M. (1994). Measuring socioeconomic status in studies of child development. *Child Development, 65*(6), 1541-1545.

Hildebrandt, V. H., Bernaards, C. M., Hofstetter, H., Collard, D., & Valkenberg H. (2015). Jeugd. In V.H. Hilde brandt, C. M. Bernaards, & H. Hofstetter (Eds.), *Trendrapport bewegen en gezondheid 2000/2014* (pp. 23-42). Leiden: TNO Gezond leven.

Hillman, C. H., Kamijo, K., & Scudder, M. (2011). A review of chronic and acute physical activity participation on neuroelectric measures of brain health and cognition during childhood. *Preventive Medicine, 52*, S21-S28.

Janssen, I., & LeBlanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity, 7*(40), 1-16.

Kriemler, S., Zahner, L., Schindler, C., Meyer, U., Hartmann, T., Hebestreit, H., et al. (2010). Effect of school based physical activity programme (KISS) on fitness and adiposity in primary schoolchildren: Cluster randomised controlled trial. *BMJ, 340*, c785.

Kristensen, P. L., Moeller, N. C., Korsholm, L., Kolle, E., Wedderkopp, N., Froberg, K., et al. (2010). The association between aerobic fitness and physical activity in children and adolescents: The European youth heart study. *European Journal of Applied Physiology, 110*(2), 267-275.

Liu-Ambrose, T., & Donaldson, M. G. (2009). Exercise and cognition in older adults: Is there a role for resistance training programmes? *British Journal of Sports Medicine, 43*(1), 25-27.

Ministry of Education, Culture and Science. (2006). *Brochure nieuwe gewichtenregeling basisonderwijs (Brochure new weighting system elementary school).* Zoetermeer: CFI.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100.

Moreau, D. (2015). Brains and brawn: Complex motor activities to maximize cognitive enhancement. *Educational Psychology Review, 27*(3), 475-482.

Poulton, R., Caspi, A., Milne, B. J., Thomson, W. M., Taylor, A., Sears, M. R., et al. (2002). Association between children's experience of socioeconomic disadvantage and adult health: A life-course study. *The Lancet, 360*(9346), 1640-1645.

Sirin, S. R. (2005). Socioeconomic status and academic achievement: A meta-analytic review of research. *Review of Educational Research, 75*(3), 417-453.

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *The Quarterly Journal of Experimental Psychology, 59*(4), 745-759.

Tomporowski, P. D., Lambourne, K., & Okumura, M. S. (2011). Physical activity interventions and children's mental function: An introduction and overview. *Preventive Medicine, 52*, S3-S9.

Twisk, J., Kemper, H. C., & van Mechelen, W. (2000). Tracking of activity and fitness and the relationship with cardiovascular disease risk factors. *Medicine and Science in Sports and Exercise, 32*(8), 1455-1461.

Welsh, M. C., et al. (2006). Executive functions in developing children: Current conceptualizations and questions for the future. In K. McCartney, & D. Philips (Eds.), *The blackwell handbook of early childhood development.* (pp. 167-187). Oxford: Blackwell Publishing Ltd.

Winter, B., Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., et al. (2007). High impact running improves learning. *Neurobiology of Learning and Memory, 87*(4), 597-609.

World Health Organization. (2010). *Global recommendations on physical activity for health.* Geneva, Switzerland: World Health Organization.

CHAPTER 2

Physical fitness and academic performance in primary school children with and without a social disadvantage[2]

Johannes W de Greeff, Esther Hartman, Marijke J Mullender-Wijnsma, Roel J Bosker, Simone Doolaard & Chris Visscher.

[2] Published in: Health Education Research, 2014, 29(5), 853-860.

ABSTRACT

This study examined the differences between children with a low socioeconomic status [socially disadvantaged children (SDC)] and children without this disadvantage (non-SDC) on physical fitness and academic performance. In addition, this study determined the association between physical fitness and academic performance, and investigated the possible moderator effect of SDC. Data on 544 children were collected and analyzed (130 SDC, 414 non-SDC, mean age = 8.0 ± 0.7). Physical fitness was measured with tests for cardiovascular and muscular fitness. Academic performance was evaluated using scores on mathematics, spelling and reading. SDC did not differ on physical fitness, compared with non-SDC, but scored significantly lower on academic performance. In the total group, multilevel analysis showed positive associations between cardiovascular fitness and mathematics [$\beta = 0.23$], and between cardiovascular fitness and spelling [$\beta = 0.16$], but not with reading. No associations were found between muscular fitness and academic performance. A significant interaction effect between SDC and cardiovascular fitness was found for spelling. To conclude, results showed a specific link between cardiovascular fitness and mathematics, regardless of socioeconomic status. SDC did moderate the relationship between cardiovascular fitness and spelling.

INTRODUCTION

Children with a low socioeconomic status [socially disadvantaged children (SDC)] are more at risk of overweight (Danielzik et al., 2004) and have a higher prevalence of health threatening conditions associated with physical inactivity, such as osteoarthritis, hypertension or chronic diseases (Adler & Ostrove, 2006). Because physical fitness is generally considered to be the ability to perform physical activity (Ortega et al., 2008), it is one of the most important health marker, as well as predictor of these health threatening conditions (Malina, 2001). It is therefore hypothesized that SDC have relatively low fitness levels compared with children without a social disadvantage (non- SDC). In addition to the lower health status, a medium-to-strong association exists between socioeconomic status and academic performance, indicating that SDC has also been linked with lower academic performance (Castelli et al., 2007; Chomitz et al., 2008; O'Dea & Mugridge, 2012; Sirin, 2005).

It is possible that low physical fitness levels and low academic performance co-occur in preadolescent children. In preadolescent children, a small number of studies reported a global positive association between physical fitness and academic performance (Castelli et al., 2007; Chomitz et al., 2008; Eveland-Sayers et al., 2009). The studies were inconclusive regarding the possible specific association. A cross-sectional study investigated the association between physical fitness and academic performance among third- and fifth-grade children, while focusing on different domains of physical fitness (cardiovascular and muscular fitness) and academic performance (mathematics and reading) (Castelli et al., 2007). Only cardiovascular fitness was positively related to both mathematics and reading. Others found that both cardiovascular and muscular fitness were associated with mathematics, but not with reading (Eveland-Sayers et al., 2009). In sum, several cross-sectional studies described the association between domains of physical fitness and academic performance. Given the mixed findings, it remains unclear whether a general or specific association exists between the different domains of physical fitness and academic performance. In addition, it is unknown whether or not SDC moderates these relations.

Several mechanisms have been proposed that might explain the positive association between physical fitness and academic performance. There is evidence that through regular participation in physical exercise of moderate (Ruiz et al., 2006) or vigorous intensity (Adler & Ostrove, 2006; Kwak et al., 2009), changes in cardiovascular fitness occur, leading to short and long-term effects on cognitive performance. Regarding the short-term effects, immediate changes in concentration levels of neurotransmitters follow after exercise. For example, exercise increases concentrations of the brain-derived neurotrophic factor (BDNF), which stimulates learning and memory (Dishman et al., 2006; Winter et al., 2007). On the long term, chronic exercise will lead to morphological brain changes, caused by upregulation of growth factors which are responsible for synaptic plasticity and neurogenesis (Dishman et al., 2006). In addition, some studies suggest that the cognitive demands that underlie exercise might improve cognitive performance (Best, 2010; Sibley & Etnier, 2003). For example, team sport games or physical education contains several cognitive challenging demands, such as setting goals, making decisions, employing different strategies and working together with teammates. The cognitive skills learned during these activities are assumed to benefit academic performance (Taras, 2005). To summarize, regular participation in exercise will lead to morphological brain changes, which benefit academic performance. Previous literature showed that lower physical fitness and lower academic performance is expected in SDC, compared with non-SDC, which is an indication that socioeconomic status is related with physical fitness and academic performance. This suggests that the association between physical fitness and academic performance can also be influenced by the socioeconomic status.

Accordingly, the first aim of this study was to examine the differences between SDC and non-SDC on physical fitness and academic performance. The second aim was to investigate the associations between different domains of physical fitness (cardiovascular and muscular fitness) and academic performance (mathematics, reading and spelling). The third aim was to examine whether SDC moderates the relation between physical fitness and academic performance.

METHODS

Participants

We obtained data from 544 primary school children of the second and third grade. All children were enrolled across 16 schools in the Northern part of the Netherlands. Children were included if they were healthy, i.e. not suffering from any physical illness or injury at the time of testing. In Table 2.1, the descriptive characteristics of the study population are shown. The study population included 286 girls and 258 boys, with 51% second-grade children (n = 277) and 49% third-grade children (n = 267). The children's mean age was 8.0 (SD = 0.7; range 7–10 years). Children were categorized in SDC or non-SDC based on the education of the person(s) who is (or are) responsible for the daily care. Data about the education were retrieved from the personal school file of each child. Children for whom both parents, or the person(s) responsible for daily care, completed less than 3 years of the secondary school were classified as SDC (n = 130) (Ministry of Education, Culture and Science, 2006). All other children were classified as non-SDC (n = 414). In addition to the SDC classification, the person responsible for the daily care (caregiver) was asked about the highest level of educational attainment, using a questionnaire. The response rate was 66.0% (n = 359). In this subsample, it appeared that for the caregiver of SDC 29.1% (n = 25) had no diploma, 51.2% (n = 44) completed secondary education and 19.8% (n = 17) completed middle-level applied education. For the caregiver of the non-SDC 3.3% (n = 9) had no diploma, 21.2% (n = 58) completed secondary education, 50.2% (n = 137) completed middle-level applied education, 19.4% (n = 53) completed higher professional education and 5.9% (n = 16) completed university. Educational levels of the caregiver of the SDC were significantly lower than those of the caregiver of the non-SDC [$U = 4088.0$, $p < 0.01$], indicating that the SDC classification was justified. The SDC classification was used in the remaining part of the study, because using the highest level of educational attainment as a measure of socioeconomic status would have resulted in considerable data loss.

Overweight and obesity were defined according to the reference values for BMI in children (Cole et al., 2000). SDC and non-SDC were comparable on all descriptive characteristics, apart from age. SDCs were significantly older compared with the non-SDCs [$t = -4.1$, $p < 0.01$]. Informed consent was obtained for all children, and all procedures were approved by the institutional Ethics Committee of the Center for Human Movement Sciences of the University Medical Center Groningen, University of Groningen.

Measurement instruments

Physical fitness was evaluated with five items of the Eurofit physical fitness test battery (Adam et al., 1988). The standardized and validated Eurofit test battery has been designed for assessment of health-related fitness in both children as well as adults (Adam et al., 1988). The test battery was administered by instructed researchers to ensure consistency in the test administration. The 20 m endurance shuttle run (Riddoch, 1990) and 10 × 5 m shuttle run were admin-

Table 2.1 Descriptive characteristics of the study population.

	SDC (n = 130)	non-SDC (n = 414)	p value
Age, years (sd)	8.3 (0.7)	8.0 (0.7)	< 0.010[a]
BMI, kg/m^2 (sd)	17.0 (2.7)	16.8 (2.6)	0.367[a]
- Overweight, n (%)[c]	25 (19)	61 (15)	0.446[b]
- Obesity, n (%)[c]	7 (5)	27 (7)	
Gender, n boys (%)	62 (48)	196 (47)	0.945[b]
Grade			
- Second, n (%)	63 (48)	214 (52)	0.521[b]
- Third, n (%)	67 (52)	200 (48)	

SDC = socially disadvantaged children, Non-SDC = children without a social disadvantage. [a]Independent t-test. [b]Non-parametric Chi-square test. [c]According to the reference values by Cole et al. (2000).

istered for measuring cardiovascular fitness. Standing broad jump (explosive strength), sit-ups (abdominal muscle endurance) and handgrip strength (static strength) were administered for measuring muscular fitness. The test battery was assessed during two regular scheduled physical education lessons on each school at the start of the school year, with approximately 1 week between the two lessons. During one lesson, the children were familiarized with the 10 × 5 m shuttle run, standing broad jump, sit-ups and handgrip strength and were given two trials for each test. The best performance was used for further analysis. During the other lesson, the 20 m endurance shuttle run was assessed and body composition (BMI) was obtained through height and weight measures. One trial was given for the 20 m endurance shuttle run.

Academic performance was evaluated with scores on mathematics and two domains of language, namely spelling and reading. For each child, the ability scores on spelling and mathematics were retrieved from the so-called child academic monitoring system. This is a standardized norm referenced test battery that is administered twice a year by most primary schools in The Netherlands. The mathematics test is an individually performed pencil and paper or digital task which consists of three subdomains, namely geometry, time and money; number sense and computation; and algebra. The reliability [*r* varied from 0.91 to 0.96], the construct validity and the content validity of the mathematics test are good (Janssen et al., 2010). The spelling test consists of two tasks. During the first task, the teacher has to read out a sentence, and repeat a given word within this sentence. The child has to write down this repeated word correctly. The second task is to recognize given words that are spelled incorrectly (de Wijs et al., 2010). The reliability [*r* varied from 0.87 to 0.92], the construct validity and the content validity of the spelling test are good (de Wijs et al., 2010). The mathematics and spelling tests were administrated at the end of the previous school year. Reading was assessed with the 1-min reading test, in which the child had to read out loud as many words as possible within 1 min (Brus & Voeten, 1973). After 1 min, the test was repeated with a different set of words. The test was administered by instructed researchers to ensure consistency in the test administration. The score was calculated as the total number of words read correctly and ranges from 0 to 232. The test has been developed for measuring technical reading skills in children from second to sixth grade. Test retest reliability [*r* varied from 0.89 to 0.92] and construct validity [*r* varied from 0.78 to 0.86] of the 1-min reading test are good (Brus & Voeten, 1973). The 1-min reading test is not part of the standardized norm-referenced test battery. The test was administrated by instructed researchers at the start of the school year. Although mathematics, spelling and reading are important domains of academic performance, it should be acknowledged that academic performance represents more that these three domains. Therefore, reference to academic performance in this study is limited to the scores on mathematics, spelling and reading.

Statistical analysis

Statistical analysis was conducted using SPSS for Windows, version 20.0. For evaluating the differences between SDC and non-SDC, analyses of covariance (ANCOVA) were conducted. The first ANCOVA included standing broad jump as the dependent variable and the SDC classification (coded as 0 = non-SDC, 1 = SDC) as the independent variable. Age, grade (coded as 0 = second grade, 1 = third grade) and gender (coded as 0 = girls, 1 = boys) were used as covariates. Because SDCs were significantly older compared with non-SDCs, both grade and age were added as covariates to control for the educational experience. The same statistical analysis was repeated for the other domains of physical fitness (sit ups, handgrip strength, 10 × 5 m shuttle run and 20 m endurance shuttle run) and for the domains of academic performance (mathematics, spelling and reading) as dependent variables. To take into account the unbalanced design, Type III sums of squares were used (Field, 2005) and effect size correlations were calculated in accordance with Rosnow et al. (2000). An effect size correlation between 0.10 and 0.30 was considered small, 0.30–0.50 moderate and above 0.50 large (Rosnow et al., 2000).

A principal component analysis was conducted to compute a Bartlett factor score for muscular fitness, summing the raw scores of standing broad jump, situps and handgrip strength and for cardiovascular fitness, summing the raw scores of the 10 × 5 m shuttle run and 20 m endurance shuttle run. The advantage of Bartlett's approach is that it produces a score which is uncorrelated with scores of other factors (Grice & Harris, 1998). Only items with loading values above 0.300 for the intended factor were included for further analysis.

To account for the common experience the children share within each school (Telford et al., 2012) and within each class, multilevel analyses were conducted (MLwiN, version 2.23). First, the raw scores of mathematics, spelling and reading performance were transformed into z-scores. The first multilevel analysis included mathematics as dependent variable. SDC, cardiovascular fitness, muscular fitness and the interaction effects between SDC and both cardiovascular and muscular fitness were used as possible predictors. Grade and gender were included as covariates. Class and school were added in the statistical model as, respectively, levels 2 and 3 and a random intercept for each school and class was considered. The same statistical analysis was repeated for spelling and reading as dependent variables. The deviances of the three models (mathematics, spelling and reading) were compared with the deviances of the covariates models, which included only the covariates (Snijders & Bosker, 2011). The final model included the covariates and the possible predictors. The interactions between SDC and both domains of physical fitness were entered in the models, investigating if SDC moderated the relationships between physical fitness and mathematics, spelling or reading performance. Effect sizes for each predictor of the multilevel models were calculated using the explained variance (R^2). The explained variance was calculated by comparing the total variance of the model including the predictor, with the total variance of the intercept only model (Snijders & Bosker, 2011). Statistical significance was adopted for all tests when $p < 0.05$.

RESULTS

There were no significant differences in physical fitness between the SDC and non-SDC (Table 2.2). Non-SDC scored significantly higher on mathematics [$p < 0.01$], spelling [$p < 0.01$] and reading [$p < 0.05$], compared with the SDC.

Table 2.2 Comparison of the SDC and non-SDC on the estimated mean score and standard errors of physical fitness and academic performance, while controlling for age, grade and gender.

	SDC (n = 130) Estimated mean (SE)	non-SDC (n = 414) Estimated mean (SE)	*p* value[c]	*ES*
Physical fitness:				
- Standing broad jump, cm[a]	122.9 (1.7)	122.2 (1.0)	0.715	0.016
- Sit-ups, n[a]	14.6 (0.4)	14.3 (0.2)	0.385	0.037
- Handgrip strength, kg[a]	13.6 (0.3)	13.1 (0.2)	0.118	0.067
- 10 × 5 m shuttle run, s[b]	24.5 (0.2)	24.3 (0.1)	0.338	0.041
- 20 m endurance shuttle run, stages[a]	3.9 (0.1)	4.0 (0.2)	0.772	0.012
Academic performance:				
- Mathematics, score[a]	47.7 (1.3)	53.8 (0.7)	< 0.010	0.170
- Spelling, score[a]	117.3 (0.6)	119.2 (0.3)	< 0.010	0.127
- Reading, score[a]	78.4 (2.4)	84.4 (1.3)	< 0.050	0.092

ES = effect size.
[a]The better the performance, the higher the score. [b]The better the performance, the lower the score. [c]ANCOVA (statistically adjusted for age, grade and gender).

The physical fitness items standing broad jump, sit-ups and handgrip strength loaded high on factor 1, representing muscular fitness (Table 2.3). The items 10 × 5 m shuttle run and 20 m endurance shuttle run loaded high on factor 2, representing cardiovascular fitness. All items loaded high on the intended factor (above 0.300) and were therefore included for further analysis.

Table 2.3 Descriptive characteristics of the study population.

	Factor 1	Factor 2
Physical fitness:		
1. Standing broad jump		0.513
2. Sit-ups		0.440
3. Handgrip strength		0.910
4. 10 × 5 m shuttle run	-0.773	
5. 20 m endurance shuttle run	0.849	
Eigenvalue	2.343	0.958
Cumulative variance explained (%)	47	66

The outcome of the multilevel models predicting the performance on mathematics, spelling and reading can be found in Table 2.4. SDC scored lower on mathematics, compared with non-SDC [β = -0.36, $p < 0.01$, $R^2 = 0.02$]. Cardiovascular fitness was positively associated with mathematics [β = 0.23, $p < 0.01$, $R^2 = 0.06$], indicating that a higher cardiovascular fitness was associated with higher scores on mathematics. No significant interaction effect was found between SDC and cardiovascular fitness, indicating that SDC did not moderate the association. SDC scored also lower on spelling [β = -0.30, $p < 0.01$, $R^2 = 0.01$]. A positive association was found between cardiovascular fitness and spelling performance [β = 0.16, $p < 0.05$, $R^2 = 0.01$]. However, a negative interaction effect was present between SDC and cardiovascular fitness [β = -0.30, $p < 0.01$, R^2 = 0.00], indicating that the association between cardiovascular fitness and spelling performance was moderated by SDC and therefore depends on whether the child has a social disadvantage or not. The interaction effect demonstrates that the positive association between cardiovascular fitness and spelling was only found in non-SDC. For reading, SDC scored significantly lower compared with non-SDC [β = -0.24, $p < 0.01$, $R^2 = 0.01$]. Both cardiovascular and muscular fitness were no significant predictors in the model, indicating that there was no association between physical fitness and reading performance.

Table 2.4 Standardized regression coëfficients *(β)* and standard errors *(SE)* for each factor predicting mathematics, spelling and reading performance.

Fixed effects	Mathematics				Spelling				Reading			
	β	SE	*p* value	R^2	β	SE	*p* value	R^2	β	SE	*p* value	R^2
Random intercept	-0.50	0.08	< 0.01		-0.37	0.10	< 0.01		-0.42	0.08	< 0.01	
Grade[a]	1.04	0.10	< 0.01	0.28	1.14	0.12	< 0.01	0.32	1.02	0.09	< 0.01	0.24
Gender[b]	0.17	0.07	< 0.05	0.01	-0.24	0.07	< 0.01	0.02	-0.05	0.08	0.540	0.00
SDC[c]	-0.36	0.08	< 0.01	0.02	-0.30	0.08	< 0.01	0.01	-0.24	0.09	< 0.01	0.01
Cardiovascular fitness	0.23	0.04	< 0.01	0.06	0.16	0.04	< 0.01	0.01	0.05	0.04	0.256	0.00
Muscular fitness	-0.05	-0.04	0.218	0.00	-0.05	0.04	0.197	0.00	-0.03	0.05	0.529	0.00
SDC*Cardiovascular	-0.12	0.08	0.112	0.01	-0.30	0.07	< 0.01	0.00	-0.15	0.08	0.064	0.00
SDC*Muscular	0.12	0.08	0.128	0.00	0.02	0.08	0.800	0.00	-0.09	0.08	0.290	0.00
Deviance			1291.54				1262.61				1368.02	
Deviance covariates model			1344.11				1299.66				1384.05	

[a]Coded as 0 for second grade, 1 for third grade. [b]Coded as 0 for girls, 1 for boys. [c]SDC = socially disadvantaged children, Coded as 0 for non-SDC, 1 for SDC.

DISCUSSION

This study showed that SDC scored significantly lower on all domains of academic performance in comparison to non-SDC. No significant differences were found for physical fitness. In the total population, cardiovascular fitness was positively associated with mathematics and spelling, but not with reading. Muscular fitness was not associated with academic performance. After taking SDC into account, the association between cardiovascular fitness and mathematics persisted, indicating that SDC did not moderate this relationship. However, SDC did moderate the relationship between cardiovascular fitness and spelling, which indicated that the positive association between cardiovascular fitness and spelling was only found in non-SDC and not in SDC.

Although the strength of the associations was small, non-SDC outperformed SDC on mathematics, spelling and reading, which is in accordance with previous literature (Chomitz et al., 2008; O'Dea & Mugridge, 2012). However, no differences on the domains of physical fitness between SDC and non-SDC were found. According to the authors' knowledge, no previous literature is available on the association between socioeconomic status and physical fitness in preadolescent children in developed countries. Previous literature did show that SDC are less likely to be physically active (Woodfield et al., 2002), which may influence children's physical fitness negatively. In this study, both groups had relative low fitness scores on standing broad jump, sit-ups and 10 × 5 m shuttle run compared to a large sample of 8-year-old Latvian children (Sauka et al., 2011). For physical fitness, the school or exercise possibilities in the neighborhood of the children might be a stronger predictor than having a social disadvantage (Ebbeling et al., 2002; Tappe et al., 2013).

A weak but significant association was found between cardiovascular fitness and multiple domains of academic performance explaining between 1 and 6% of the variance, whereas muscular fitness was not related with any of the domains. In accordance with these results, another study showed that only cardiovascular fitness was positively related with academic performance in preadolescent children (8–11 years), and not muscular fitness (Castelli et al., 2007). This specific positive association extends the evidence for the cardiovascular fitness hypothesis (North et al., 1990). This hypothesis states that through regular participation in physical exercise of moderate (Ruiz et al., 2006) or vigorous intensity (Kwak et al., 2009; Ortega et al., 2008), changes in cardiovascular fitness occur, which will lead to increased cerebral blood flow. On the long term, chronic exercise will lead to upregulation of growth factors, responsible for synaptic plasticity and neurogenesis (Winter et al., 2007). For example, exercise increases concentrations of the BDNF, which stimulates learning and memory (Dishman et al., 2006).

Small positive associations between cardiovascular fitness and the domains mathematics and spelling were found in the total population but not between cardiovascular fitness and reading. These results are partly in accordance with other cross-sectional studies. A stronger association was found between total physical fitness scores and scores on mathematics compared to scores on English (Chomitz et al., 2008). Others found an association between cardiovascular fitness and mathematics, but no association with reading (Telford et al., 2012). From these results, combined with our results, it seems that the association between cardiovascular fitness and mathematics is consistent in school-aged children. Although it should be acknowledged that genetic factors may have played a role and that it is easier to increase physical activity than to change physical fitness, a possible way to improve the mathematical performance in both SDC as non-SDC might be improving their cardiovascular fitness. This causality for mathematics is supported by a quasi-experimental study which reported a positive benefit of physical education on especially mathematical performance (Shephard et al., 1984). It is also supported by a randomized controlled intervention study which reported a significant improvement in mathematics, but not reading, after a cardiovascular exercise program (Davis et al., 2011).

Strengths of this study include the statistical control for the effects on school and class level. The effect of the school and class culture might play a dominant role in the relation between physical fitness and academic performance (Telford et al., 2012). The advantage of multilevel analyses is that it takes into account the nested variability of children within each school (Snijders & Bosker, 2011). A limitation of this study is the cross-sectional design, which makes it unable to confirm any type of causality. It is therefore not possible to confirm that increasing physical fitness causes increased performance on mathematics. Second, although a binary classification of socioeconomic status is commonly used in literature (Chomitz et al., 2008), it may partly account for the limited effects found between SDC and non- SDC in this study. The advantage of using the current classification is that it can be obtained from the personal school files of the children.

In conclusion, this study shows that SDC have a comparable physical fitness but are still behind in academic performance, compared with non-SDC attending to the same school. A positive association between cardiovascular fitness and spelling performance was found in non-SDC and between cardiovascular fitness and mathematics for non-SDC, as well as SDC. This finding is relevant in understanding the academic performance of preadolescent children given the worldwide pressure on and importance of improving academic performance (Chomitz et al., 2008).

REFERENCES

Adam, C., et al. (1988). *EUROFIT: European test of physical fitness*. Rome: Council of Europe, Committee for the Development of Sport.

Adler, N. E., & Ostrove, J. M. (2006). Socioeconomic status and health: What we know and what we don't. *Annals of the New York Academy of Sciences, 896*(1), 3-15.

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review, 30*(4), 331-351.

Brus, B. T., & Voeten, M. (1973). *Een minuut test: Verantwoording en handleiding (One minute test: Manual).* Nijmegen: Berkhout.

Castelli, D. M., Hillman, C. H., Buck, S. M., & Erwin, H. E. (2007). Physical fitness and academic achievement in third- and fifth-grade students. *Journal of Sport and Exercise Psychology, 29*(2), 239-252.

Chomitz, V. R., Slining, M. M., McGowan, R. J., Mitchell, S. E., Dawson, G. F., & Hacker, K. A. (2008). Is there a relationship between physical fitness and academic achievement? positive results from public school children in the Northeastern United States. *Journal of School Health, 79*(1), 30-37.

Cole, T. J., Bellizzi, M. C., Flegal, K. M., & Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: International survey. *BMJ, 320*(7244), 1-6.

Danielzik, S., Czerwinski-Mast, M., Langnäse, K., Dilba, B., & Müller, M. (2004). Parental overweight, socioeconomic status and high birth weight are the major determinants of overweight and obesity in 5–7 y-old children: Baseline data of the Kiel Obesity Prevention Study (KOPS). *International Journal of Obesity, 28*(11), 1494-1502.

Davis, C. L., Tomporowski, P. D., McDowell, J. E., Austin, B. P., Miller, P. H., Yanasak, N. E., et al. (2011). Exercise improves executive function and achievement and alters brain activation in overweight children: A randomized, controlled trial. *Health Psychology, 30*(1), 91-98.

De Wijs, A., Kamphuis, F., Kleintjes, F., Tomesen, M. (2010). *Spelling voor groep 3 tot en met 6: Wetenschappelijke verantwoording (Scientific justification for spelling examination in first-fourth grade)*. Arnhem: Cito.

Dishman, R. K., Berthoud, H., Booth, F. W., Cotman, C. W., Edgerton, V. R., Fleshner, M. R., et al. (2006). Neurobiology of exercise. *Obesity, 14*(3), 345-356.

Ebbeling, C. B., Pawlak, D. B., & Ludwig, D. S. (2002). Childhood obesity: Public-health crisis, common sense cure. *The Lancet, 360*(9331), 473-482.

Eveland-Sayers, B. M., Farley, R. S., Fuller, D. K., Morgan, D. W., & Caputo, J. L. (2009). Physical fitness and academic achievement in elementary school children. *Journal of Physical Activity & Health, 6*(1), 99-104.

Field, A. (2005). *Discovering statistics using SPSS for windows: Advanced techniques for beginners (Introducing statistical methods series)*. London: Sage Publications Limited.

Grice, J. W., & Harris, R. J. (1998). A comparison of regression and loading weights for the computation of factor scores. *Multivariate Behavioral Research, 33*(2), 221-247.

Janssen, J., Verhelst, N., Engelen, R., Scheltens, F. (2010). *Wetenschappelijke verantwoording van de toesten Rekenen-Wiskunde voor groep 3 tot en met 8 (Scientific justification for mathematics examination in first-fifth grade)*. Arnhem: Cito.

Kwak, L., Kremers, S. P. J., Bergman, P., Ruiz, J. R., Rizzo, N. S., & Sjöström, M. (2009). Associations between physical activity, fitness, and academic achievement. *The Journal of Pediatrics, 155*(6), 914-918.

Malina, R. M. (2001). Physical activity and fitness: Pathways from childhood to adulthood. *American Journal of Human Biology, 13*(2), 162-172.

Ministry of Education, Culture and Science. (2006). *Brochure nieuwe gewichtenregeling basisonderwijs (Brochure new weighting system elementary school)*. Zoetermeer: CFI.

North, T. C., McCullagh, P., & Tran, Z. V. (1990). Effect of exercise on depression. *Exercise and Sport Sciences Reviews,18*(1), 379-415.

O'Dea, J. A., & Mugridge, A. C. (2012). Nutritional quality of breakfast and physical activity independently predict the literacy and numeracy scores of children after adjusting for socioeconomic status. *Health Education Research, 27*(6), 975-985.

Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity, 32*(1), 1-11.

Riddoch, C. (1990). *Northern Ireland fitness survey-1989: The fitness, physical activity, attitudes and lifestyles of Northern Ireland post-primary schoolchildren*. Belfast: Division of Physical and Health Education, The Queen's University of Belfast.

Rosnow, R. L., Rosenthal, R., & Rubin, D. B. (2000). Contrasts and correlations in effect-size estimation. *Psychological Science, 11*(6), 446-453.

Ruiz, J. R., Rizzo, N. S., Hurtig-Wennlöf, A., Ortega, F. B., Wärnberg, J., & Sjöström, M. (2006). Relations of total physical activity and intensity to fitness and fatness in children: The European Youth Heart Study. *The American Journal of Clinical Nutrition, 84*(2), 299-303.

Sauka, M., Priedite, I. S., Artjuhova, L., Larins, V., Selga, G., Dahlström, Ö, et al. (2011). Physical fitness in Northern European youth: Reference values from the Latvian physical health in youth study. *Scandinavian Journal of Public Health, 39*(1), 35-43.

Shephard, R. J., et al. (1984). Required physical activity and academic grades: A controlled study. In J. Ilmarinen, & I. Valimaki (Eds.), *Children and sport* (pp. 58-63). Berlin: Springer-Verlag.

Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: A meta-analysis. *Pediatric Exercise Science, 15*(3), 243-256.

Sirin, S. R. (2005). Socioeconomic status and academic achievement: A meta-analytic review of research. *Review of Educational Research, 75*(3), 417-453.

Snijders, T., & Bosker, R. (2011). *Multilevel analysis: An introduction to basic and advanced multilevel modeling*. London: Sage Publications Limited.

Tappe, K. A., Glanz, K., Sallis, J. F., Zhou, C., & Saelens, B. E. (2013). Children's physical activity and parents' perceptionof the neighborhood environment: Neighborhood impact on kids study. *International Journal of Behavioral Nutrition and Physical Activity, 10*(1), 39.

Taras, H. (2005). Physical activity and student performance at school. *Journal of School Health, 75*(6), 214-218.

Telford, R. D., Cunningham, R. B., Telford, R. M., & Abharatna, W. P. (2012). Schools with fitter children achieve better literacy and numeracy results: Evidence of a school cultural effect. *Pediatric Exercise Science, 24*(1), 45-57.

Winter, B., Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., et al. (2007). High impact running improves learning. *Neurobiology of Learning and Memory, 87*(4), 597-609.

Woodfield, L., Duncan, M., Al-Nakeeb, Y., Nevill, A. M., & Jenkins, C. (2002). Sex, ethnic and socio-economic differences in children's physical activity. *Pediatric Exercise Science, 14*, 277-285.

CHAPTER 3

The relationship between socioeconomic status and executive functions: Is there a mediating role of physical fitness?[3]

Johannes W de Greeff, Esther Hartman, Marijke J Mullender-Wijnsma, Simone Doolaard, Roel J Bosker & Chris Visscher.

[3]Submitted

ABSTRACT

Children with a social disadvantage are at risk for a low physical fitness and seem to underperform on executive functions in comparison with children without a social disadvantage. The first aim was to investigate the direct relations between social disadvantage, physical fitness and executive functions in primary school children. The second aim was to examine whether physical fitness mediates the relationship between social disadvantage and executive functions. Data on 431 children were collected. Children were categorized as socially disadvantaged children (SDC) or children without a social disadvantage (non-SDC) according to the parental education level (91 SDC, 340 non-SDC, age = 8.2 ± 0.7, mean ± SD). Physical fitness was evaluated with five items of the Eurofit, measuring muscular and cardiovascular fitness. Executive functions were evaluated with the Stroop (inhibition), Digit and Visual span backward (verbal and visual working memory) and M-WCST (cognitive flexibility). Results showed that SDC scored significantly lower on cognitive flexibility [η_p^2= 0.015], compared with non-SDC. No differences were found between SDC and non-SDC on physical fitness. Regression analysis showed a small positive relation between aerobic capacity and cognitive flexibility [β = 0.16]. Results from the mediation analysis showed that physical fitness did not mediate the relationship between social disadvantage and executive functions. Increasing cardiovascular fitness in both SDC as well as non-SDC might be beneficial for cognitive tasks that require cognitive flexibility.

INTRODUCTION

The importance of executive functions for children has recently received increased interest, given the crucial role in mental health, and the positive relation with academic performance (Diamond, 2013; St Clair-Thompson & Gathercole, 2006). Much of the development of executive functions and the underlying neural circuitry in the prefrontal cortex occurs during childhood (ages 6-12), making it sensitive for environmental experiences of the child (Best et al., 2009). Executive functions consist of distinct, yet related domains, including at least: (a) inhibition, the ability to deliberately suppress an automatic, dominant or prepotent response, (b) working memory, the ability of updating and monitoring information and (c) cognitive flexibility, the ability to change between mental sets or tasks (Miyake et al., 2000). Maintaining or improving physical fitness through regular exercise might be one of the key experiences that positively influences the developmental trajectory of executive functions (Stroth et al., 2009). This is supported by an increasing number of studies which report a general benefit of physical fitness on cognition, with most of the evidence found for executive functions (also called executive control or cognitive control) in adult studies (Colcombe & Kramer, 2003). The relationship between physical fitness and executive functions in children is less well understood.

Possible relations between physical fitness and executive functions could especially be of importance in children with a low socioeconomic status (Socially Disadvantaged Children; SDC), as it is well-documented that SDC are at risk for a low physical fitness (Duncan et al., 1994; Poulton et al., 2002) and score low on executive functions (Ardila et al., 2005; Noble et al., 2007; Waber et al., 2006). Waber et al. (2006) studied 9-12 year old SDC and compared several neurocognitive functions with their norm scores. It was found that more errors were made on tests measuring executive functions, such as working memory and planning. A cross-sectional study, in which the correlations between degree of social disadvantage and eight different executive function tasks were investigated in 5- to 14-year-old children, found a significant positive correlation between 0.20 and 0.46 on most tasks (six out of eight) (Ardila et al., 2005). Several studies have argued that a poor physical health is one of the possible mediators that might explain the relationship between socioeconomic status and general well-being (Bradley & Corwyn, 2002; Noble et al., 2007). Similarly, it can be argued that physical fitness might mediate the association between social disadvantage and executive functions.

Physical fitness, in part genetically determined, but also highly influenced by environmental factors, is defined as the capacity to perform physical activity (Ortega et al., 2008). Physical fitness includes at least two main domains: (a) cardiovascular fitness, the capacity of the cardiovascular and respiratory system to perform prolonged strenuous exercise, and (b) muscular fitness, the capacity of the muscles to perform work against a resistance. Although research is limited, in two cross-sectional studies the relationship between physical fitness and executive functions in primary school children (6-12 years) has been examined. Results showed a small positive relation between cardiovascular fitness and an inhibition task, explaining between 5 - 9% of the variance (Buck et al., 2008). In the second study, children scoring relatively high on cardiovascular fitness also scored relatively high on a working memory task, indicating a moderate positive relation between physical fitness and working memory [η^2 = 0.11](Chaddock et al., 2011). In both studies, cardiovascular fitness was used as a measure of physical fitness, as well as only one domain of executive functions, limiting the evidence for a general relationship between physical fitness and executive functions.

Chronic exercise aimed at improving physical fitness will lead to physiological changes in the brain, which might have long term positive effects on executive functions (Stroth et al., 2009). For example, concentration levels of growth factors responsible for synaptic plasticity and neurogenesis are increased (Dishman et al., 2006). Cross-sectional studies investigating the event-related potentials offer a further understanding of the underlying mechanisms involved in the possible relation between physical fitness and executive functions. The event-related potentials reflect the voltage pattern of a neuroelectric signal occurring before or during stimulus or response. Especially the P3 component, which occurs directly after a stimulus, gives information on how the brain processes a stimulus response task. The amplitude of the P3 component represents the amount of allocated attention during the task, while the latency has been related with stimulus processing speed (Polich & Kok, 1995). A higher cardiovascular fitness was strongly related with a higher P3 amplitude [η^2 = 0.17] and a faster P3 latency [η^2 = 0.17] during a working memory task (Hillman et al., 2005). During an inhibition task, a moderate relationship was found between cardiovascular fitness and a higher P3 amplitude [η^2 = 0.12], while no relation was found between cardiovascular fitness and P3 latency (Hillman et al., 2009). Despite small differences between the results of working memory and inhibition, these findings suggest a positive relation between cardiovascular fitness and multiple domains of executive functions.

To summarize, along with the clear evidence of the relationship between social disadvantage and executive functions, physical fitness might also be related with executive functions, with moderate results coming from inhibition and working memory. The aim of the present study was therefore to investigate the direct relations between social disadvantage, physical fitness and executive functions in primary school children. The second aim was to examine whether physical fitness mediates the relations between social disadvantage and executive functions.

METHODS

Participants

Data was obtained from 507 second and third graders (394 non-SDC and 113 SDC) across twelve different primary schools in the Northern part of the Netherlands (mean age = 8.1 ± 0.7). Of these children, 431 were included and 76 were excluded (18%) because of absence at the time of testing (Table 3.1). Children of which both parents, or the person(s) responsible for daily care, completed less than three years of secondary education were classified as SDC (n = 91) (Ministry of Education, Culture and Science, 2006). The other children were classified as non-SDC (n = 340). Information of the classification (SDC or non-SDC) was retrieved from the personal school file of each child. SDC and non-SDC were comparable on all descriptive characteristics, apart from age. SDC were significantly older compared with the non-SDC [$t = -2.9$, $p = 0.003$]. The current study was conducted with prior approval of the institutional Ethics Committee of the Center for Human Movement Sciences of the University Medical Center Groningen, University of Groningen and informed consent was obtained for all children.

Table 3.1 Descriptive characteristics of the included study population.

	SDC (n = 91)	non-SDC (n = 340)	*p* value
Age, years (SD)	8.4 (0.7)	8.1 (0.7)	0.003[a]
BMI, kg/m^2 (SD)	17.1 (2.8)	16.9 (2.7)	0.493[a]
- Normal weight, n (%)[c]	68 (75)	263 (77)	0.727[b]
- Overweight, n (%)[c]	17 (19)	52 (15)	
- Obesity, n (%)[c]	6 (7)	25 (7)	
Sex, n boys (%)	41 (45)	149 (44)	0.905[b]
Grade			
- Second, n (%)	44 (48)	175 (52)	0.638[b]
- Third, n (%)	47 (52)	165 (48)	

SD = Standard deviation, SDC = socially disadvantaged children, Non-SDC = children without a social disadvantage.
[a]Independent t-test. [b]Non-parametric Chi-square test. [c]According to the reference values by Cole et al. (2012).

Physical fitness

Physical fitness was evaluated with five items of the Eurofit physical fitness test battery (Adam et al., 1988). The selected items were standing broad jump (SBJ, explosive strength, in cm), sit-ups in 30 s (SUP, muscular endurance, in number of completed sit-ups) and handgrip strength (HG, static strength, in kg) for measuring muscular fitness. The 10 × 5 m shuttle run (10 × 5 m

SR, speed-coordination, in s) and the 20 m endurance shuttle run (20 m SR, aerobic capacity, in number of stages) were administered for measuring cardiovascular fitness. The standardized and validated Eurofit test battery has been designed for assessment of health-related fitness in both children as well as adults (Adam et al., 1988). The test-retest reliability [*r* varied from 0.62 to 0.97] and construct validity of the five items are adequate for children (van Mechelen et al., 1991). The five items were assessed during two regular scheduled physical education lessons. During one lesson, the SBJ, SUP, HG and 10 × 5 m SR were assessed in a circuit form. During the other physical education lesson, the 20 m SR was assessed and BMI was obtained through height and weight measures. Two trials were given for the SBJ, HG and 10 × 5 m SR with the best performance used for further analysis. One trial was given for the SUP and 20 m SR. Instructed researchers administered the test battery to ensure consistency in the test administration.

Executive functions

Inhibition

Inhibition was measured using the Golden Stroop test (Strauss et al., 2006). Children are asked to read aloud 100 color words printed in black ink (word card), to name the colors of 100 solid squares (color card), and to name the colors of 100 incongruent color words (color-word card) as fast as possible. In all three conditions, children are asked to name as many items as they can in 45 seconds. The color-word condition requires the greatest amount of inhibitory control because the child has to read aloud the color of the word and suppress the automatic response of reading the word. An interference score was computed by subtracting the number of correctly named colors in the color-word condition from the number of correctly named colors in the color condition. The score ranges from 0 to 100. The test re-test reliabilities of the word condition, color condition and color-word condition can be considered good [respectively 0.88, 0.82 and 0.73] (Jensen, 1965).

Working memory

The Digit span backward and the Visual span backward, both part of the Wechsler Memory Scale Revised (Wechsler, 1987), were used for measuring respectively verbal and spatial working memory. During the Digit span task the child was asked to recall a sequence of spoken digits in reverse order. The instructor gave the child one practice trial in order to ensure that the child understood the test. The number of digits in each span increases from two to eight, with three sequences in each span. The test stops when the child fails to recall two of the three sequences in a span. The score is the total number of correctly recalled sequences and ranges from 0 to 21. The Visual span task consists of a card containing eight printed squares. The child was asked to repeat tapping sequences in reverse order that increases from two to seven squares, with two sequences in each span. Again, the instructor gave one practice trial in order to ensure that the child understood the test. The test stops when the child fails to recall both sequences in a span. The score is the total number of correctly tapped sequences and ranges from 0 to 12. The test re-test reliability coefficients for the Digit span backward [$r = 0.82$] and the Visual span backward [$r = 0.75$] indicate that both tests are reliable within children. Factor analysis on a standardized sample showed high factor loadings on general working memory for the Digit span backward [loading = 0.75] and the Visual span backward [loading = 0.65], indicating that both tests are a valid measure for working memory (Wechsler, 1987).

Cognitive flexibility

Cognitive flexibility was measured using the modified Wisconsin card sorting test (M-WCST). The M-WCST consists of four stimulus cards and 48 response cards. Each card contains figures that vary in form (triangle, cross, circle or star), number (one, two, three or four) and color (yellow, red, green, or blue). The examiner places the four stimulus cards in a row in front of the child and instructs the child to match each response card with one of the four stimulus cards. The child is told whether the card is sorted right or wrong. After six consecutive correct responses the sorting category is changed and the examiner instructs the child to find another rule. The test ends after six categories are correctly sorted or after all 48 cards are sorted. A categorizing efficiency was calculated by scoring six points for every completed category and awarding one point for each of the 48 cards not used (Cianchetti et al., 2007). The categorizing efficiency ranges from 0 to 48. The M-WCST is particularly suitable for children, because it takes less time to administer and is less stressful compared with the original WCST (Cianchetti et al., 2007). Although currently no reliability and validity scores are present in children, moderate test-retest reliability correlations were found within adults [0.56 and 0.64 for number of categories and perseverative error respectively] (Lineweaver et al., 1999; Schretlen, 2010). The M-WCST has a strong correlation with part B of the Trail Making Test [r = -0.52], which is considered a reliable test measuring cognitive flexibility (Schretlen, 2010). Children were tested individually by instructed researchers in a quiet room at the start of the school year, approximately two weeks before measuring physical fitness.

Statistical analysis

To investigate the relations between social disadvantage and executive functions, while accounting for the family wise error between the four items of executive functions, a MANCOVA was calculated and univariate analyses were obtained, with scores on the Stroop interference, Digit span backward, Visual span backward and M-WCST as dependent variables; social disadvantage (coded as 0 = non-SDC, 1 = SDC) as the independent variable; age as a covariate. Age was included as a covariate because the SDC were significantly older. To investigate the relations between social disadvantage and physical fitness, a second MANCOVA was conducted with scores on SBJ (cm), SUP (n), HG (kg), 10 × 5 m SR (s) and 20 m SR (stage) as dependent variables; social disadvantage as independent variable; age as a covariate. Effect sizes were calculated using the partial eta squared (η_p^2), which represents the strength of the association between the independent variable and the dependent variable. A η_p^2 below 0.06 is considered small, 0.07 - 0.14 medium and above 0.14 strong (Stevens, 1996).

The mediation bootstrapping approach was used to investigate the relationship between physical fitness and executive functions and to test the mediation effect of physical fitness, as suggested by Preacher and Hayes (Preacher & Hayes, 2008). The mediation approach makes a distinction between direct effect, indirect effect and total effect. The total effect in the current study is the prediction of executive functions from social disadvantage. The indirect effect is the prediction of executive functions from social disadvantage through physical fitness. The direct effect is the prediction of executive functions from social disadvantage, after taking account of the mediation effect of physical fitness (i.e. total effect = direct effect + indirect effect). The mediation approach tests whether the total effect of social disadvantage on executive functions is significantly reduced after the addition of physical fitness to the model. For the mediation approach, social disadvantage was used as the independent variable; SBJ, SUP, HG, 10 × 5 m SR and 20 m SR as proposed mediators; age as covariate and Stroop interference as dependent variable. Similar statistical analyses were conducted with Digit span backward, Visual span backward and M-WCST as dependent variables. 95% Confidence intervals (*CI*) were calculated for the indirect effect of the domains of physical fitness using 5000 bootstrap samples. If zero was not between the lower and upper bound of the *CI*, significance was adopted. A more detailed discussion on bootstrapping can be found elsewhere (Shrout & Bolger, 2002). Effect sizes were calculated using Cohen's f^2. An f^2 below 0.39 is considered small, 0.40 - 0.59 medium and above 0.59 strong (Cohen, 1988).

Bonferroni adjusted p-values were used for univariate and mediation analyses, indicating that statistical significance was adopted when $p < 0.013$ ($p < 0.05$ divided through 4) (Field, 2005). Statistical significance for all other tests was adopted when $p < 0.05$. All calculations were performed using SPSS v.20.0 software for Windows.

RESULTS

Social disadvantage and executive functions

Table 3.2 shows the estimated mean scores for SDC and non-SDC on executive functions after controlling for age. Univariate analyses showed that SDC, compared with non-SDC, scored significantly lower on the M-WCST [$F(1,430) = 6.6$, $p = 0.010$, $\eta_p^2 = 0.015$], but no significant differences were found for Stroop interference [$F(1,430) = 0.8$, $p = 0.383$], Digit span backward [$F(1,430) = 2.9$, $p = 0.091$], or Visual span backward [$F(1,430) = 4.0$, $p = 0.047$]. All effect sizes were small.

Social disadvantage and physical fitness

Univariate analyses showed no significant differences between SDC and non-SDC for SBJ [$F(1,430) = 0.1$, $p = 0.810$], SUP [$F(1,430) = 0.1$, $p = 0.715$], HG [$F(1,430) = 2.0$, $p = 0.158$], 10 × 5 m SR [$F(1,430) = 2.2$, $p = 0.141$] or 20 m SR [$F(1,430) = 0.4$, $p = 0.520$] (Table 3.2).

Table 3.2 Comparison of the SDC and non-SDC on the estimated mean score and standard errors (SE) of executive functions and physical fitness, while controlling for age.

	SDC (n = 91) Mean (SE)	non-SDC (n = 340) Mean (SE)	*p* value[c]
Executive functions:			
Stroop interference[a], score	17.1 (0.8)	17.9 (0.4)	0.383
Digit span backward[b], correct items	4.8 (0.2)	5.1 (0.1)	0.091
Visual span backward[b], correct items	5.3 (0.2)	5.7 (0.1)	0.047
M-WCST[b], category efficiency score	18.6 (1.2)	22.0 (11.8)	0.010
Physical fitness:			
SBJ[b], cm	124.9 (1.1)	124.3 (1.1)	0.810
SUP[b], n	15.4 (0.4)	15.3 (0.2)	0.715
HG[b], kg	13.9 (0.3)	13.4 (0.2)	0.158
10 × 5 m SR[a], s	24.9 (0.3)	24.4 (0.1)	0.141
20 m SR[a], stages	3.9 (0.2)	4.1 (0.1)	0.520

SDC = socially disadvantaged children, Non-SDC = children without a social disadvantage, M-WCST = modified Wisconsin card sorting test, SBJ = standing broad jump, SUP = sit-ups, HG = handgrip strength, 10 × 5 m SR = 10 × 5 m shuttle run, 20 m SR = 20 m shuttle run. [a]The better the performance, the lower the score. [b]The better the performance, the higher the score. [c]ANCOVA (statistically adjusted for age).

Physical fitness and executive functions

The results obtained from the mediation approach showed that the 20 m SR was positively related with the M-WCST [β = 0.16, p = 0.004], indicating that a higher score on the 20 m SR is related with a higher score on the M-WCST. The total model explained 6% of the variance [f^2 = 0.058]. No significant relations were found between the domains of physical fitness and the Stroop interference, Digit span backward and Visual span backward (Table 3.3).

Physical fitness as a mediator

The mediation approach showed that the total estimated effect of social disadvantage on executive functions was significantly negative for the M-WCST [β = -0.30, p = 0.010](Table 3). No significant total estimated effect of social disadvantage was found for the Stroop interference [β = -0.10, p = 0.383], Digit span backward [β = -0.20, p = 0.091], or Visual span backward [β = -0.23, p = 0.047]. The direct estimated effects of social disadvantage on Stroop interference [β = -0.08, p = 0.490], Digit span backward [β = -0.18, p = 0.126], Visual span backward [β = -0.21, p = 0.070], and M-WCST [β = -0.29, p = 0.015], were non-significant. The results showed that the estimated effects of social disadvantage for executive functions through physical fitness (indirect effect) were not significant for Stroop interference, Digit span backward, Visual span backward and M-WCST. This indicates physical fitness did not mediate the relationship between social disadvantage and executive functions.

Table 3.3 Regression analysis predicting the performance of executive functions with the domains of physical fitness and social disadvantage while controlling for gender and age: standardized regression coëfficiënts (*β*) and standard errors (*SE*).

	Stroop interference		Digit span backward		Visual span backward		M-WCST	
	β (SE)	p value	β (SE)	p value	β (SE)	p value	β (SE)	p value
Control variable:								
Age	0.10 (0.08)	0.178	0.14 (0.08)	0.072	0.20 (0.07)	0.007	0.17 (0.07)	0.020
Mediators:								
SBJ	0.04 (0.06)	0.567	0.14 (0.06)	0.016	-0.04 (0.06)	0.515	-0.02 (0.06)	0.770
SUP	-0.03 (0.06)	0.555	-0.10 (0.06)	0.071	0.00 (0.06)	0.972	-0.03 (0.06)	0.543
HG	-0.04 (0.06)	0.552	-0.09 (0.06)	0.129	0.03 (0.06)	0.625	0.06 (0.06)	0.319
10x5m SR	-0.08 (0.06)	0.202	0.00 (0.06)	0.976	-0.12 (0.06)	0.054	-0.06 (0.06)	0.314
20m SR	0.02 (0.06)	0.700	0.08 (0.06)	0.178	0.04 (0.06)	0.486	0.16 (0.06)	0.004
Independent variable:								
Social disadvantage (T[a])	-0.10 (0.12)	0.383	-0.20 (0.12)	0.091	-0.23 (0.12)	0.047	-0.30 (0.12)	0.010
Social disadvantage (D[a])	-0.08 (0.12)	0.490	-0.18 (0.12)	0.126	-0.21 (0.12)	0.070	-0.29 (0.12)	0.015
Bootstrapping mediation:								
	95%-CI		95%-CI		95%-CI		95%-CI	
	Lower	Upper	Lower	Upper	Upper	Lower	Lower	Upper
SBJ	-0.012	0.028	-0.029	0.051	-0.030	0.012	-0.022	0.013
SUP	-0.035	0.009	-0.045	0.020	-0.016	0.018	-0.030	0.010
HG	-0.041	0.007	-0.058	0.003	-0.010	0.039	-0.006	0.046
10x5m SR	-0.061	0.004	-0.022	0.032	-0.083	0.003	-0.064	0.006
20m SR	-0.032	0.008	-0.055	0.008	-0.037	0.007	-0.065	0.022

Social disadvantage: 0 = non-SDC, 1 = SDC. M-WCST = modified Wisconsin card sorting test, SBJ = standing broad jump, SUP = sit-ups, HG = handgrip strength, 10x5m SR = 10x5m shuttle run, 20m SR = 20m shuttle run.
[a]The effect of social disadvantage on executive functions, without (T; total effect) and with (D; direct effect) including the mediation effect of physical fitness.

DISCUSSION

The current study found that SDC scored lower on cognitive flexibility compared with non-SDC, that no differences were found between SDC and non-SDC on physical fitness and that aerobic capacity was positively related with cognitive flexibility. Although physical fitness did not mediate the relationship between social disadvantage and executive functions, aerobic capacity and social disadvantage were significant predictors for cognitive flexibility in primary school children.

According to the authors knowledge, this is the first study that examined the relationship between cardiovascular fitness and executive functions in children using multiple domains of executive functions in the same study. Based on the current findings, it can be concluded that aerobic capacity is related with cognitive flexibility. The finding that cardiovascular fitness is not related with inhibition and verbal working memory is in contrast with previous literature, which stated that a general rather than a selective relationship exists between cardiovascular fitness and executive functions (Hillman et al., 2009). In addition, previous literature reported a relationship between cardiovascular fitness and both working memory and inhibition (Chaddock et al., 2011; Dishman et al., 2006). Earlier studies including both children and adults argued that the relationship between cardiovascular fitness and executive functions is explained by the increase of both gray and white matter in the prefrontal brain areas (Colcombe et al., 2006; Madsen et al., 2010). Although this might explain that cardiovascular fitness is related with executive functions rather than other cognitive functions, it remains unclear why the current study found a relationship only with cognitive flexibility. Future research is therefore needed to better understand the complex relationship between cardiovascular fitness and executive functions.

The results also showed that aerobic capacity, but not muscular fitness was related with cognitive flexibility. Few studies focused on the relationship between muscular fitness and executive functions. While possible different mechanisms might be present between children and adults, muscular fitness training in adults increases concentration levels of neurotransmitters, such as the insulin-like growth factor I, which promotes neuronal survival, differentiation and growth (Liu-Ambrose & Donaldson, 2009). A meta-analytic study showed that combined muscular and cardiovascular training resulted in a larger improvement of executive functions [*ES* = 0.59], compared with cardiovascular training only [*ES* = 0.41] in older adults (Poulton et al., 2002). However, since muscular training is thought to merely prevent a cognitive decline in older adults (Liu-Ambrose & Donaldson, 2009), the improvement in executive functions might not be as effective within primary school children. This is supported by a study investigating the relationship between physical fitness and academic performance, using cardiovascular and muscular domains. It was found that the relationship between physical fitness and academic performance in third and fifth grade children was present for cardiovascular and not for muscular fitness (Castelli et al., 2007).

Several limitations of the current study should be noted to provide a basis for further exploration. Although the current mediating variable analysis provides estimates of causal pathways, randomized controlled intervention studies are needed to provide insight into the actual causal effects of physical fitness on executive functions. Second, a binary classification of socioeconomic status is commonly used in literature (Chomitz et al., 2008), however, different results might have been observed when using a more continuous classification. The SDC classification is a standardized system in the Netherlands, used for the weighted student funding as a means of financing primary schools. The advantage of using such classification is that it can be obtained from the personal school file of the school administration record system without data loss. A more detailed discussion of the weighted student funding and the policy that introduced this classification can be found elsewhere (Driessen & Dekkers, 2008). We did not have access to more detailed socioeconomic data. The relative large sample of children, the multiple domains of physical fitness and executive functions, and the direct testing of the mediation effect using the bootstrapping approach are notable strengths of this study.

The current study showed that social disadvantage and aerobic capacity were related with cognitive flexibility; children with a social disadvantage or lower aerobic capacity scored lower on cognitive flexibility. Physical fitness did not mediate the relationship between social disadvantage and executive functions in children. Finding no relation between social disadvantage and physical fitness makes it likely that the lower performance on cognitive flexibility shown by SDC is explained by other factors, but does not take away the importance of cardiovascular fitness in executive functioning in children. Increasing cardiovascular fitness in both SDC as well as non-SDC might be beneficial for cognitive tasks that require cognitive flexibility.

REFERENCES

Adam, C., et al. (1988). *EUROFIT: European test of physical fitness*. Rome: Council of Europe, Committee for the Development of Sport.

Ardila, A., Rosselli, M., Matute, E., & Guajardo, S. (2005). The influence of the parents' educational level on the development of executive functions. *Developmental Neuropsychology, 28*(1), 539-560.

Best, J. R., Miller, P. H., & Jones, L. L. (2009). Executive functions after age 5: Changes and correlates. *Developmental Review, 29*(3), 180-200.

Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Review of Psychology, 53*(1), 371-399.

Buck, S. M., Hillman, C. H., & Castelli, D. M. (2008). The relation of aerobic fitness to Stroop task performance in preadolescent children. *Medicine and Science in Sports and Exercise, 40*(1), 166-172.

Castelli, D. M., Hillman, C. H., Buck, S. M., & Erwin, H. E. (2007). Physical fitness and academic achievement in third- and fifth-grade students. *Journal of Sport and Exercise Psychology, 29*(2), 239-252.

Chaddock, L., Hillman, C. H., Buck, S. M., & Cohen, N. J. (2011). Aerobic fitness and executive control of relational memory in preadolescent children. *Medicine & Science in Sports & Exercise, 43*(2), 344-349.

Chomitz, V. R., Slining, M. M., McGowan, R. J., Mitchell, S. E., Dawson, G. F., & Hacker, K. A. (2008). Is there a relationship between physical fitness and academic achievement? Positive results from public school children in the Northeastern United States. *Journal of School Health, 79*(1), 30-37.

Cianchetti, C., Corona, S., Foscoliano, M., Contu, D., & Sannio-Fancello, G. (2007). Modified Wisconsin card sorting test (MCST, MWCST): Normative data in children 4–13 years old, according to classical and new types of scoring. *The Clinical Neuropsychologist, 21*(3), 456-478.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale NJ: Lawrence Erlbaum Associates.

Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., et al. (2006). Aerobic exercise training increases brain volume in aging humans. *The Journals of Gerontology: Series A, Biological Sciences and Medical Sciences, 61*(11), 1166-1170.

Colcombe, S. J., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science, 14*(2), 125-130.

Cole, T., & Lobstein, T. (2012). Extended international (IOTF) body mass index cut-offs for thinness, over weight and obesity. *Pediatric Obesity, 7*(4), 284-294.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135-168.

Dishman, R. K., Berthoud, H., Booth, F. W., Cotman, C. W., Edgerton, V. R., Fleshner, M. R., et al. (2006). *Neurobiology of exercise. Obesity, 14*(3), 345-356.

Driessen, G., & Dekkers, H. (2008). Dutch policies on socio–economic and ethnic inequality in education. *International Social Science Journal, 59*, 449-464.

Duncan, G. J., Brooks-Gunn, J., & Klebanov, P. K. (1994). Economic deprivation and early childhood development. *Child Development, 65*(2), 296-318.

Field, A. (2005). *Discovering statistics using SPSS for windows: Advanced techniques for beginners (Introducing statistical methods series)*. London: Sage Publications Limited.

Hillman, C. H., Buck, S. M., Themanson, J. R., Pontifex, M. B., & Castelli, D. M. (2009). Aerobic fitness and cognitive development: Event-related brain potential and task performance indices of executive control in preadolescent children. *Developmental Psychology, 45*(1), 114-129.

Hillman, C. H., Castelli, D. M., & Buck, S. M. (2005). Aerobic fitness and neurocognitive function in healthy preadolescent children. *Medicine and Science in Sports and Exercise, 37*(11), 1967-1974.

Jensen, A. R. (1965). Scoring the Stroop test. *Acta Psychologica, 24*, 398-408.

Lineweaver, T. T., Bondi, M. W., Thomas, R. G., & Salmon, D. P. (1999). A normative study of Nelson's (1976) modified version of the Wisconsin card sorting test in healthy older adults. *The Clinical Neuropsychologist, 13*(3), 328-347.

Liu-Ambrose, T., & Donaldson, M. G. (2009). Exercise and cognition in older adults: Is there a role for resistance training programmes? *British Journal of Sports Medicine, 43*(1), 25-27.

Madsen, K. S., Baaré, W. F., Vestergaard, M., Skimminge, A., Ejersbo, L. R., Ramsøy, T. Z., et al. (2010). Response inhibition is associated with white matter microstructure in children. *Neuropsychologia, 48*(4), 854-862.

Ministry of Education, Culture and Science. (2006). *Brochure nieuwe gewichtenregeling basisonderwijs (Brochure new weighting system elementary school)*. Zoetermeer: CFI.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100.

Noble, K., McCandliss, B., & Farah, M. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental Science, 10*(4), 464-480.

Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity, 32*(1), 1-11.

Polich, J., & Kok, A. (1995). Cognitive and biological determinants of P300: An integrative review. *Biological Psychology, 41*(2), 103-146.

Poulton, R., Caspi, A., Milne, B. J., Thomson, W. M., Taylor, A., Sears, M. R., et al. (2002). Association between children's experience of socioeconomic disadvantage and adult health: A life-course study. *The Lancet, 360*(9346), 1640-1645.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods, 40*(3), 879-891.

Schretlen, D. (2010). *Modified Wisconsin card sorting test (M-WCST)*. Lutz FL: Psychological Assessment Resources. Shrout, P. E., & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods, 7*(4), 422-445.

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. The Quarterly Journal of *Experimental Psychology, 59*(4), 745-759.

Stevens, J. (1996). Applied multivariate statistics for the social sciences (3th ed.). Mahwah NJ: Lawrence Erlbaum Associates.

Strauss, E. H., et al. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary*. New York: Oxford University Press.

Stroth, S., Kubesch, S., Dieterle, K., Ruchsow, M., Heim, R., & Kiefer, M. (2009). Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Research, 1269,* 114-124.

Van Mechelen, W., et al. (1991). *Eurofit: Handleiding met referentieschalen voor 12- tot en met 16-jarige jongens en meisjes in Nederland (manual with referencevalues for 12-16 year old boys and girls in the Netherlands)*. Haarlem: De Vrieseborch.

Waber, D. P., Gerber, E. B., Turcios, V. Y., Wagner, E. R., & Forbes, P. W. (2006). Executive functions and performance on high-stakes testing in children from urban schools. *Developmental Neuropsychology, 29*(3), 459-477.

Wechsler, D. (1987). *WMS-R: Wechsler memory scale-revised: Manual*. San Antonio: Psychological Corporation.

CHAPTER 4

Effect of physically active academic lessons on body mass index and physical fitness in primary school children[4]

Johannes W de Greeff, Esther Hartman, Marijke J Mullender-Wijnsma, Roel J Bosker, Simone Doolaard & Chris Visscher.

[4]Published in: Journal of School Health, 2016, 86(5):346-352.

ABSTRACT

Background: Preventing overweight and improving physical fitness in primary school children is a worldwide challenge, and physically active intervention programs usually come with the cost of academic instruction time. This study aimed to investigate effects of physically active academic lessons on body mass index (BMI) and physical fitness in primary school children. Methods: Dutch children attending second- or third-grade class from 12 primary schools [N = 376, 8.1 ± 0.7 years] were randomly assigned to a 22-week intervention program or to the control group. In addition to measuring BMI before and after the intervention, physical fitness was measured with 5 items of the Eurofit test battery, measuring cardiovascular and muscular fitness. Results: Multilevel analysis showed a significant interaction effect between condition (intervention vs control) and grade [$B = -0.47$, $p < 0.05$]. For third-grade children, BMI of the intervention group did not change significantly during the intervention period, whereas a significant increase was found in the control group. No significant main or interaction effects were found for cardiovascular or muscular fitness. Conclusions: The current physically active academic lessons had positive effects on BMI in third-grade children, but had no effects on cardiovascular and muscular fitness.

INTRODUCTION

Overweight and obesity in primary school children are an important risk factor for numerous health problems, including a cluster of cardiometabolic risk factors such as hypertension, insulin resistance, and increased levels of blood lipids (Bailey et al., 2012; Boddy et al., 2014). It is known that many of these risk factors persist into adulthood (Singh et al., 2008) and that physical inactivity in children contributes to the development of overweight and obesity (Dobbins et al., 2013). Nevertheless, primary school children in the Netherlands still spend the majority of their school time (66%) in sedentary activities and less than 5% in moderate to vigorous activities (van Stralen et al., 2014). The school setting is an important environment to promote physical activity and prevent overweight and obesity, because children spend a large part of their day in the school environment (Pate et al., 2006). In addition, physical activity in schools is associated with a higher on-task behavior (Mahar et al., 2006) and could also positively influence academic performance (Erwin et al., 2012).

Preventing overweight by improving children's body composition, as measured by body mass index (BMI), has proven to be difficult in school-based interventions (Demetriou & Höner, 2012; Harris et al., 2009). A meta-analysis that included randomized controlled trials and controlled clinical trials found no significant effect of a variety of physical activity interventions designed to improve BMI in children (Harris et al., 2009). A possible explanation for this finding is that the intensity of the physical activity was insufficient or that there may have been small effects in overweight children, but this effect is not likely to be found when studying the entire study population (Harris et al., 2009).

Regular physical activity in at least moderate to vigorous physical activity (MVPA) results in an improvement of cardiovascular fitness (Kristensen et al., 2010), which is an important predictor of physical health in children (Ortega et al., 2008). Six out of 11 intervention programs aiming to improve cardiovascular fitness through MVPA were effective according to a systematic review including controlled and randomized controlled trials within the school setting (Kriemler et al., 2011). Although a general relationship between MVPA and cardiovascular fitness in children is weak to moderate (Kristensen et al., 2010; Strong et al., 2005), moderate to strong associations were found in children with initially low levels of physical activity [$\beta = 0.63$] (Kristensen et al., 2010). This suggests that intervention programs might especially be effective in increasing the level of cardiovascular fitness in children with relatively low levels of physical activity or fitness.

The focus of intervention programs is often limited to cardiovascular fitness, with less or no attention focused on muscular fitness (Kriemler et al., 2011). Including muscular fitness as one of the outcome measures is nevertheless recommended (Janssen & LeBlanc, 2010), given that an inverse association has been found between muscular fitness and metabolic risk factors, independent of cardiovascular fitness (Smith et al., 2014; Steene-Johannessen et al., 2009). Nevertheless, only 2 out of 11 intervention programs included muscular fitness (Kriemler et al., 2011). One study was unable to find a significant improvement in muscular fitness, while still finding an improvement in cardiovascular fitness (Sollerhed & Ejlertsson, 2008). The other study did not find an improvement in both domains of physical fitness (Verstraete et al., 2007). Given the competing curriculum demands and the high pressure on teachers to increase the academic performance (Erwin et al., 2012), programs that focus on improving physical fitness usually come with the cost of academic instruction time, making it difficult to implement. A more promising strategy is to include physical activity during learning activities in the classroom (Donnelly et al., 2009; Riley et al., 2014). Being physically active during a time in which the children are normally required to sit still may lead to a decrease in BMI and improvements in muscular and cardiovascular fitness. Previous literature has shown that after 8 months of physically active academic lessons (based on TAKE 10!), the BMI of 6- to 12-year-old girls who participated in the daily 10-minute intervention program significantly decreased (-0.47 kg/m^2), compared to girls in the control group (0.66 kg/m^2) (Liu et al., 2007). Another study has shown that similar physically active academic lessons significantly slowed the increasing rate of BMI (1.8 percentile increase of BMI for the intervention group vs 2.4 percentile increase for the control group) and showed significant positive results on reading, mathematics, and spelling (Donnelly et al., 2009). Effects on physical fitness were not included, and therefore, unknown at this point. Granted the inverse association with health and psychological risks, and the positive association with academic performance, effects on physical fitness are an important outcome measure for physically active academic lessons (Janssen & LeBlanc, 2010; Pate et al., 2006).

The aim of this study was to investigate effects of physically active academic lessons on BMI and physical fitness in primary school children in the Netherlands. It was hypothesized that being physically active during these lessons would decrease BMI and increase physical fitness. In addition, it was expected that possible effects are larger for children with an initially higher BMI and lower levels of physical fitness. This study is part of the project ‘‘Fit en Vaardig op school’’ (fit and academically proficient at school; F&V), which is a randomized controlled trial including a school-based intervention program for primary school children with the primary aim to improve academic performance. The intervention program contains lessons that include simple, individual physical exercises during routine learning activities such as mathematics, spelling, and reading tasks in the classroom (Mullender-Wijnsma et al., 2015).

METHODS

Participants

Data were obtained from 388 children across 12 different schools in the Northern part of the Netherlands. From every school, the second- or third-grade class was randomly assigned to the intervention group. Randomization was performed by the national Bureau for Economic Policy Analysis that was not involved in the study. The class that was not assigned to the intervention group formed the control group. Ten outliers and 2 children who attended less than 80% of the intervention lessons were excluded from further analyses. The final study sample consisted of 6 second and 6 third-grade classes in the intervention group (n = 181), and 6 second- and 6 third-grade classes in the control group (n = 195). The descriptive characteristics of the study population are shown in Table 4.1. No differences were found between the control and the intervention group, apart from age and grade. A higher percentage of third-grade children were included in the control group [B = -0.11, $t(371)$ = 2.20, $p < 0.05$] and because of this, the control group was significantly older compared to the intervention group [B = -0.23, $t(371)$ = 3.14, $p < 0.05$]. No significant age differences between the control and intervention group were found when investigating the second- [B = -0.09, $t(185)$ = 1.05, p = 0.297] and third-grade children [B = -0.13; $t(181)$ = 1.27; p = 0.080] separately. Informed consent was obtained for all children.

Table 4.1 Baseline characteristics of children in the intervention and control group.

	Control (n = 195)	Intervention (n = 181)	p value[a]
Age (yr)	8.2 ± 0.8	8.0 ± 0.7	0.002
Height (cm)	132.5 ± 6.9	131.5 ± 6.6	0.145
Weight (kg)	29.6 ± 6.1	29.2 ± 5.8	0.480
Overweight	31 (16)	34 (19)	0.726
Obesity	10 (5)	9 (5)	
Grade			
Second	88 (45)	102 (56)	0.029
Third	107 (55)	79 (44)	
Sex			
Girls	115 (59)	100 (55)	0.518
Boys	80 (41)	81 (45)	

Values are mean ± SD for continuous or n (%) for overweight, obesity, grade and sex.
n = number of participants.
[a]Multilevel regression analysis to account for clustered data.

Instruments

Children were weighed to the nearest 0.1 kg (Model Clara 803, Seca, Chino, CA) and standing height was measured to the nearest cm using a portable stadiometer (Model Seca 220, Seca). Body mass index was calculated as weight (kg)/height (m^2). Overweight and obesity were defined according to the reference values for BMI in children (Cole et al., 2000). Physical fitness was evaluated with 5 items of the Eurofit physical fitness test battery (Adam et al., 1988). The standardized and validated Eurofit test battery has been designed for assessment of health-related fitness in both children as well as adults (van Mechelen et al., 1991). The selected items were 10 × 5 m shuttle run (10 × 5 m SR, speed-coordination, in seconds, s) and the 20 m endurance shuttle run (20 m SR, cardiorespiratory endurance, in number of completed stages) for measuring cardiovascular fitness. The standing broad jump (SBJ, explosive strength, in cm), sit-ups in 30 s (SUP, muscular endurance, in number of completed sit-ups), and handgrip strength (HG, static strength, in kg) were administered for measuring muscular fitness. The test-retest reliability (*r* varied from 0.62 to 0.97) and construct validity of the 5 items are adequate for children (van Mechelen et al., 1991).

Procedure

F&V is a 2-year cluster-randomized controlled trial of a school-based intervention program, focusing on integrating physical activity into the routine academic lessons such as mathematics, spelling, and reading tasks in the regular education classroom. For example, the children had to solve a mathematical problem by giving the answer with the correct number of jumps (2 times 3 is 6 jumps). Learning activities were matched with the regular learning activities, resulting in a different program for second- and third-grade children. The physical exercises were aimed to be of moderate to vigorous intensity, yet relatively easy to perform. Results of an implementation study showed that the MVPA engagement, measured during the lessons with heart rate monitors, was on average 64% of the time (around 16 minutes of MVPA) (Mullender-Wijnsma et al., 2015). Six substitute teachers, who were hired and trained to deliver the intervention lessons, took over the control of the classroom from the regular teacher during the lessons, which was delivered 3 times a week, 30 minutes each time for 22 weeks. During each lesson, 10-15 minutes were spent on solving math problems followed by 10- 15 minutes on solving language problems. A detailed description of the intervention and its implementation has been described elsewhere (Mullender-Wijnsma et al., 2015). The physical fitness test battery was assessed during 2 regularly scheduled physical education classes at the start of the school year (pretest) and directly after the intervention period of 22 weeks (posttest). The 10 × 5 m SR, SBJ, SUP, and HG were assessed in a circuit form during one physical education class. The children were familiarized with the tests and were given one trial for the SUP and 2 trials for the 10 × 5 m SR, SBJ, and HG. The best performance was used for further analysis. During another class, the 20 m SR was assessed and BMI was obtained through height and weight measures. One trial was given for the 20 m SR. Height and weight were measured while the children were wearing gym clothes without shoes. Instructed researchers administered the test battery following the standardized protocol (van Mechelen et al., 1991) to ensure consistency in the test administration.

Data analysis

Multilevel regression analyses were conducted for descriptive analyses and to assess the possible differences between the control and intervention group before the intervention, for second- and third-grade children separately. A random intercept was considered for each child (level 1) and for each school (level 2), to account for the common experience the children share within each school. The outcome measures of the pretest, BMI (kg/m^2), SBJ (cm), SUP (n), HG (kg), 10 × 5 m SR (s), and 20 m SR (stage), were used as the dependent variables and condition (intervention or control) as the independent variable. To assess the possible differences between the intervention and control group after the intervention, multilevel regression analyses were conducted. A random intercept was considered for each child (level 1) and for each school (level 2). The outcome measure of the posttest (BMI, SBJ, SUP, HG, 10 × 5 m SR, or 20 m SR) was treated as dependent variable and condition as an independent variable (condition model). Sex, age, grade, and the corresponding scores of the pretest were treated as covariates. To investigate whether there were different intervention effects for second-grade compared to third-grade children, the inclusion of the interaction between condition and grade was considered as an additional independent variable (condition × grade model). In the third and final model (condition × baseline model), the inclusion of the interaction between condition and pretest score was considered to investigate whether the possible effect of the intervention depended on the pretest scores. The model fit was evaluated by comparing the deviance of the covariates model, which included only the covariates, with the final model (Snijders & Bosker, 2011). Statistical significance was adopted for all tests when $p < 0.05$. All statistical analyses were conducted using MLwiN (version 2.29).

RESULTS

Table 4.2 shows the mean scores of the pretest for BMI and the domains of physical fitness. Within second-grade children and within third-grade children, no significant differences were found between the control and intervention group. This indicates that for BMI and for the domains of physical fitness, the control group did not differ from intervention group before the intervention.

Table 4.2 Comparison of the pretest scores for BMI and the domains of physical fitness for the control and intervention group.

	Second grade		Third grade	
	Control (n = 88)	Intervention (n = 102)	Control (n = 107)	Intervention (n = 79)
BMI (kg/m^2)	16.3 ± 2.1	16.6 ± 2.4	17.1 ± 2.6	17.0 ± 2.3
SBJ (cm)[a]	117.5 ± 18.1	122.0 ± 18.9	133.5 ± 21.5	127.5 ± 21.1
SUP (number of sit-ups)[a]	14.6 ± 4.4	14.9 ± 3.9	16.2 ± 3.9	15.9 ± 3.9
HG (kg)[a]	12.1 ± 3.1	12.7 ± 2.6	14.7 ± 2.9	14.3 ± 3.4
10 × 5 m SR (seconds)[b]	25.0 ± 3.0	24.9 ± 2.0	23.4 ± 2.1	24.2 ± 3.0
20 m SR (stages)[a]	4.0 ± 2.0	3.8 ± 1.6	4.2 ± 1.9	4.3 ± 1.8

Values are mean ± SD. No significant differences were found between the control and intervention group using multilevel regression analysis to account for clustered data.
n = number of participants, BMI = body mass index, SBJ = standing broad jump, SUP = sit-ups, HG = handgrip strength, 10 × 5 m SR = 10 × 5 m shuttle run, 20 m SR = 20 m endurance shuttle run.
[a]A higher score indicates a better performance. [b]A lower score indicates a better performance.

No significant difference was found between the intervention and control group on BMI posttest scores in the condition model (Table 4.3). Including condition and the interaction between condition and grade significantly improved the covariance model [$\Delta\chi^2(2) = 6.7$, $p < 0.05$]. The significant interaction between condition and grade [$B = -0.47$, $t(369) = 2.03$, $p < 0.05$] indicated that the intervention effect was different for third-grade compared to second-grade children. Figure 4.1 shows the predicted pretest and posttest BMI values based on the condition × grade model. Within the third grade, BMI of children in the control group increased significantly during the intervention period, whereas BMI of children in the intervention group did not change significantly. This interaction effect was not found within second-grade children. Including the interaction between condition and pretest scores did not improve the model, indicating that the intervention effect did not depend on the pretest scores. For the domains of physical fitness, including condition did not improve the model fit. This indicates that no significant differences were found on the posttest scores between the intervention and control group after controlling for sex, age, grade, pretest scores, and accounting for the clustered structure of the data. Including the interaction between condition and grade, or the interaction between condition and pretest scores, did not improve the model indicating that the effects did not depend on grade or pretest scores.

Table 4.3 Multilevel models predicting the posttest scores for BMI and each item of physical fitness, accounting for the clustering of data at school level and controlling for sex, age, grade and the pretest scores.

	BMI			SBJ			SUP			HG			10 × 5 m SR			20 m SR		
	B[a]	SE	p	B[a]	SE	p	B[a]	SE	p	B[a]	SE	p	B[a]	SE	p	B[a]	SE	p
Random intercept	0.04	0.59	.941	39.08	11.89	**.001**	9.56	2.85	**.001**	-1.22	1.64	.460	10.27	1.85	< **.001**	1.13	1.17	.333
Sex[b]	-0.05	0.07	.466	2.04	1.46	.162	0.35	0.35	.313	0.19	0.20	.343	-0.28	0.18	.124	0.56	0.15	< **.001**
Age	0.00	0.08	.053	0.77	1.54	.616	-0.64	0.37	.090	0.68	0.22	**.003**	-0.09	0.19	.632	0.05	0.15	.764
Grade[c]	0.08	0.11	.434	1.90	2.15	.378	1.98	0.52	< **.001**	0.00	0.30	.992	-0.02	0.27	.944	-0.14	0.22	.503
Pretest	0.99	0.02	< **.001**	0.61	0.04	< **.001**	0.72	0.05	< **.001**	0.79	0.04	< **.001**	0.62	0.04	< **.001**	0.66	0.04	< **.001**
Condition[d]	-0.12	0.07	.082	2.55	1.40	.071	0.13	0.34	.712	0.06	0.20	.780	0.13	0.18	.466	0.05	0.14	.742
Deviance Covariance model			771.16			3036.84			1973.35			1561.34			1468.23			1293.30
Deviance Condition model			768.12			3033.57			1973.21			1561.26			1467.70			1293.19

BMI = body mass index, SBJ = standing broad jump, SUP = sit-ups, HG = handgrip strength, 10 × 5 m SR = 10 × 5 m shuttle run, 20 m SR = 20 m endurance shuttle run.
[a]Unstandardized regression coëfficient. [b,c,d]Respectively girls, second grade and control group are coded as 0. Boys, third grade and intervention group are coded as 1.

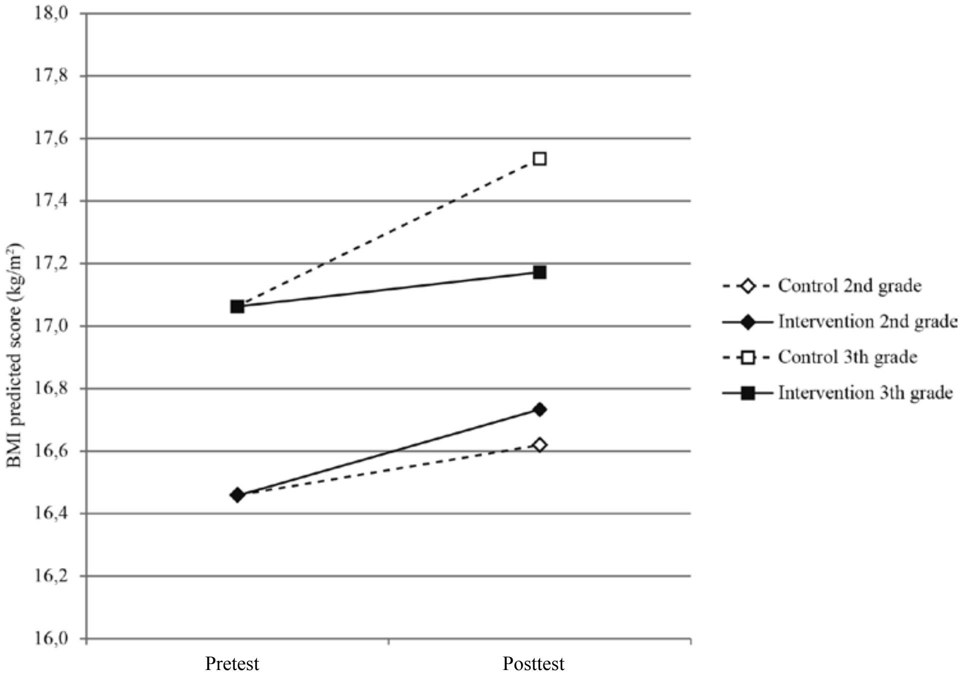


Figure 4.1 Predicted pretest and posttest values for Body Mass Index (BMI) for second- and third-grade children.

DISCUSSION

The aim of this study was to investigate effects of physically active academic lessons on BMI and physical fitness in primary school children. It was hypothesized that possible effects are larger for children with an initially higher BMI and lower levels of physical fitness. The results of this study show that the physically active academic lessons had a significant effect on the BMI of third-grade children. The BMI of the intervention group did not change significantly, whereas a significant increase was found in the control group during the intervention period. No significant effects were found on physical fitness.

Improving BMI through school-based interventions is known to be challenging and intervention studies were mostly unsuccessful (Demetriou & Höner, 2012; Harris et al., 2009). In this study, the BMI of the third-grade children in the intervention group did not change whereas the BMI of the control group increased, indicating that the lessons might prevent overweight and obesity in third-grade children. Previous literature argued that small effects of a subset of children in the intervention could not be noticeable in the assessment of the entire study population (Harris et al., 2009; Magnusson et al., 2012). A secondary aim of this study was therefore to investigate possible effects in children with initially higher BMI; however, no effect for children with initially higher BMI was found. The positive effects on BMI in third-grade children are comparable with the physical activity across the curriculum (PAAC) study, showing a significantly smaller increase in BMI for schools that delivered the lessons more than 75 minutes per week after 3 years (Donnelly et al., 2009). Considering that the current lesson time was close to 75 minutes per week (Mullender-Wijnsma et al., 2015), this study has shown that positive effects on BMI can even be found after an intervention period of 22 weeks.

Physically active academic lessons also have the potential to improve physical fitness (Donnelly et al., 2009), but these effects have not been published in previous studies. This study showed that the intervention had no effect on muscular or cardiovascular fitness. A meta-analysis that investigated the effects of school-based physical activity programs argued that a lack of significant effects could be due to the intensity of the program (Harris et al., 2009). Heart rate monitoring results of the current lessons showed that the MVPA engagement was on average 16 minutes (Mullender-Wijnsma et al., 2015). This duration of MVPA is comparable with the average time spend in MVPA during a physical education lesson in Dutch primary school children, which is around 18 minutes (Slingerland et al., 2011). School-based physical activity programs with comparable intensity and duration had a positive (Kriemler et al., 2010; Sollerhed & Ejlertsson, 2008), or no effect on physical fitness in 6- to 12-year-old children (Boyle-Holmes et al., 2010; Verstraete et al., 2007). It therefore remains unclear which intensity and duration are needed to improve physical fitness in primary school children. Although more intense physical exercises of the lessons might have improved physical fitness, high intensity exercises during physically active academic lessons can have a negative impact on the academic tasks (Kamijo et al., 2004). Nonetheless, because the children are mostly physically inactive during the school time (van Stralen et al., 2014), the lessons likely decreased sedentary time which can have beneficial health effects in children (Verloigne et al., 2012).

Limitations

There are some limitations in this study that should be considered. Although this study controlled for several possible confounders such as sex, age, grade, and school, there are still some potential confounders that may have affected the results. We did not take into account differences in motivation for the exercises or after-school activities. It is therefore unclear whether or not the increase of physical activity during the school time affected the physical activity after school or during the weekends. The primary strengths of this study were the cluster-randomized controlled trial design and the fact that the program was integrated in the school curriculum and directed at all the children in the class, which avoided selection bias in the intervention group.

Conclusions

The physically active academic lessons had positive effects on BMI in third-grade children during a time in which the children normally have to sit quiet, but the lessons did not affect physical fitness. The intensity of the lessons might need to be further increased in order to positively impact BMI and physical fitness in all children.

Implications

Children spend a lot of their school time in sedentary behavior (van Stralen et al., 2014). Reducing the time spend in this behavior and promoting physical activity during school time can have important health benefits. One of the biggest barriers for teachers to promote physical activity in primary schools are their own perceptions toward physical activity and their lack of knowledge about how to improve it (Riley et al., 2014). The current physically active academic lessons provide primary school teachers a novel strategy to integrate physical activity into the routine academic lessons that is both feasible and does not come with the cost of academic instruction time (Mullender-Wijnsma et al., 2015). A potentially important benefit that might lower the barriers for teachers (and school directors) is that physically active academic lessons might not only provide health benefits but might also enhance academic performance (Donnelly & Lambourne, 2011; Erwin et al., 2012; Riley et al., 2014). This study has shown that the current lessons have significant health benefits that are associated with an improved BMI in third-grade children. To improve physical fitness in children, the intensity of physically active academic lessons might need to be higher.

REFERENCES

Adam, C., et al. (1988). *EUROFIT: European test of physical fitness*. Rome: Council of Europe, Committee for the Development of Sport.

Bailey, D. P., Boddy, L. M., Savory, L. A., Denton, S. J., & Kerr, C. J. (2012). Associations between cardiorespiratory fitness, physical activity and clustered cardiometabolic risk in children and adolescents: The HAPPY study. *European Journal of Pediatrics, 171*(9), 1317-1323.

Boddy, L. M., Murphy, M. H., Cunningham, C., Breslin, G., Foweather, L., Gobbi, R., et al. (2014). Physical activity, cardiorespiratory fitness, and clustered cardiometabolic risk in 10- to 12-year-old school children: The REACH Y6 study. *American Journal of Human Biology: The Official Journal of the Human Biology Council, 26*(4), 446-451.

Boyle-Holmes, T., Grost, L., Russell, L., Laris, B. A., Robin, L., Haller, E., et al. (2010). Promoting elementary physical education: Results of a school-based evaluation study. Health Education & Behavior: *The Official Publication of the Society for Public Health Education, 37*(3), 377-389.

Cole, T. J., Bellizzi, M. C., Flegal, K. M., & Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: International survey. *BMJ, 320*(7244), 1-6.

Demetriou, Y., & Höner, O. (2012). Physical activity interventions in the school setting: A systematic review. *Psychology of Sport and Exercise, 13*(2), 186-196.

Dobbins, M., Husson, H., DeCorby, K., & LaRocca, R. L. (2013). School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6 to 18. *Cochrane Database Syst Rev, 2*, CD007651.

Donnelly, J. E., & Lambourne, K. (2011). Classroom-based physical activity, cognition, and academic achievement. *Preventive Medicine, 52*, S36-S42.

Donnelly, J. E., Greene, J. L., Gibson, C. A., Smith, B. K., Washburn, R. A., Sullivan, D. K., et al. (2009). Physical activity across the curriculum (PAAC): A randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. *Preventive Medicine, 49*(4), 336-341.

Erwin, H., Fedewa, A., Beighle, A., & Ahn, S. (2012). A quantitative review of physical activity, health, and learning outcomes associated with classroom-based physical activity interventions. *Journal of Applied School Psychology, 28*(1), 14-36.

Harris, K. C., Kuramoto, L. K., Schulzer, M., & Retallack, J. E. (2009). Effect of school-based physical activity interventions on body mass index in children: A meta-analysis. *CMAJ: Canadian Medical Association Journal = Journal De L'Association Medicale Canadienne, 180*(7), 719-726.

Janssen, I., & LeBlanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity, 7*(40), 1-16.

Kamijo, K., Nishihira, Y., Hatta, A., Kaneda, T., Wasaka, T., Kida, T., et al. (2004). Differential influences of exercise intensity on information processing in the central nervous system. *European Journal of Applied Physiology, 92*(3), 305-311.

Kriemler, S., Meyer, U., Martin, E., van Sluijs, E. M., Andersen, L. B., & Martin, B. W. (2011). Effect of school-based interventions on physical activity and fitness in children and adolescents: A review of reviews and systematic update. *British Journal of Sports Medicine, 45*(11), 923-930.

Kriemler, S., Zahner, L., Schindler, C., Meyer, U., Hartmann, T., Hebestreit, H., et al. (2010). Effect of school - based physical activity programme (KISS) on fitness and adiposity in primary schoolchildren: Cluster randomised controlled trial. *BMJ, 340*, c785.

Kristensen, P. L., Moeller, N. C., Korsholm, L., Kolle, E., Wedderkopp, N., Froberg, K., et al. (2010). The association between aerobic fitness and physical activity in children and adolescents: The European Youth Heart Study. *European Journal of Applied Physiology, 110*(2), 267-275.

Liu, A., Hu, X., Ma, G., Cui, Z., Pan, Y., Chang, S., et al. (2007). Report on childhood obesity in China (6) evaluation of a classroom-based physical activity promotion program. *Biomedical and Environmental Sciences, 20*(1), 19-23.

Magnusson, K. T., Hrafnkelsson, H., Sigurgeirsson, I., Johannsson, E., & Sveinsson, T. (2012). Limited effects of a 2-year school-based physical activity intervention on body composition and cardiorespiratory fitness in 7-year-old children. *Health Education Research, 27*(3), 484-494.

Mahar, M. T., Murphy, S. K., Rowe, D. A., Golden, J., Shields, A. T., & Raedeke, T. D. (2006). Effects of a classroom-based program on physical activity and on-task behavior. *Medicine and Science in Sports and Exercise, 38*(12), 2086-2094.

Mullender-Wijnsma, M. J., Hartman, E., de Greeff, J. W., Bosker, R. J., Doolaard, S., & Visscher, C. (2015). Improving academic performance of school-age children by physical activity in the classroom: Year one program evaluation. *Journal of School Health, 85*(6), 365-371.

Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity, 32*(1), 1-11.

Pate, R. R., Davis, M. G., Robinson, T. N., Stone, E. J., McKenzie, T. L., Young, J. C., et al. (2006). Promoting physical activity in children and youth: A leadership role for schools: A scientific statement from the American Heart Association Council on nutrition, physical activity, and metabolism (physical activity committee) in collaboration with the councils on cardiovascular disease in the young and cardiovascular nursing. *Circulation, 114*(11), 1214-1224.

Riley, N., Lubans, D. R., Holmes, K., & Morgan, P. J. (2014). Rationale and study protocol of the EASY minds (encouraging activity to stimulate young minds) program: Cluster randomized controlled trial of a primary school-based physical activity integration program for mathematics. *BMC Public Health, 14*(1), 816.

Singh, A. S., Mulder, C., Twisk, J. W., van Mechelen, W., & Chinapaw, M. J. (2008). Tracking of childhood overweight into adulthood: A systematic review of the literature. *Obesity Reviews, 9*(5), 474-488.

Slingerland, M., Oomen, J., & Borghouts, L. (2011). Physical activity levels during Dutch primary and secondary school physical education. *European Journal of Sport Science, 11*(4), 249-257.

Smith, J. J., Eather, N., Morgan, P. J., Plotnikoff, R. C., Faigenbaum, A. D., & Lubans, D. R. (2014). The health benefits of muscular fitness for children and adolescents: A systematic review and meta-analysis. *Sports Medicine, 44*(9), 1209-1223.

Snijders, T., & Bosker, R. (2011). *Multilevel analysis: An introduction to basic and advanced multilevel modeling.* London: Sage Publications Limited.

Sollerhed, A. C., & Ejlertsson, G. (2008). Physical benefits of expanded physical education in primary school: Findings from a 3–year intervention study in Sweden. Scandinavian *Journal of Medicine & Science in Sports, 18*(1), 102-107.

Steene-Johannessen, J., Anderssen, S. A., Kolle, E., & Andersen, L. B. (2009). Low muscle fitness is associated with metabolic risk in youth. *Medicine and Science in Sports and Exercise, 41*(7), 1361-1367.

Strong, W. B., Malina, R. M., Blimkie, C. J., Daniels, S. R., Dishman, R. K., Gutin, B., et al. (2005). Evidence based physical activity for school-age youth. *The Journal of Pediatrics, 146*(6), 732-737.

Van Mechelen, W., et al. (1991). *Eurofit: Handleiding met referentieschalen voor 12- tot en met 16-jarige jongens en meisjes in Nederland (manual with referencevalues for 12-16 year old boys and girls in the Netherlands).* Haarlem: De Vrieseborch.

van Stralen, M. M., Yıldırım, M., Wulp, A., te Velde, S. J., Verloigne, M., Doessegger, A., et al. (2014). Measured sedentary time and physical activity during the school day of European 10- to 12-year-old children: The ENERGY project. *Journal of Science and Medicine in Sport, 17*(2), 201-206.

Verloigne, M., Van Lippevelde, W., Maes, L., Yildirim, M., Chinapaw, M., Manios, Y., et al. (2012). Levels of physical activity and sedentary time among 10- to 12-year-old boys and girls across 5 European countries using accelerometers: An observational study within the ENERGY-project. *International Journal of Behavioral Nutrition and Physical Activity, 9*(1), 34-41.

Verstraete, S. J., Cardon, G. M., De Clercq, D. L., & De Bourdeaudhuij, I. M. (2007). A comprehensive physical activity promotion programme at elementary school: The effects on physical activity, physical fitness and psychosocial correlates of physical activity. *Public Health Nutrition, 10*(5), 477-484.

CHAPTER 5

Long-term effects of physically active academic lessons on physical fitness and executive functions in primary school children[5]

Johannes W de Greeff, Esther Hartman, Marijke J Mullender-Wijnsma, Roel J Bosker, Simone Doolaard & Chris Visscher.

[5]Published in: Health Education Research, 2016, 31(2):185-194.

ABSTRACT

Integrating physical activity into the curriculum has potential health and cognitive benefits in primary school children. The aim of this study was to investigate the effects of physically active academic lessons on cardiovascular fitness, muscular fitness and executive functions. In the current randomized controlled trial, 499 second and third graders within 12 primary schools (mean age = 8.1 ± 0.7) were randomized to the intervention (n = 249) or control condition (n = 250). The physically active academic lessons were given for 2 consecutive school years, 22 weeks per year, three times a week, with a duration of 20–30 min per lesson. Multiple tests were administered before, between and after the intervention period, measuring cardiovascular fitness, muscular fitness and executive functions. Multilevel analysis accounted for the nested structure of the children within classes and schools. Results showed a larger improvement in speed-coordination [$B = -0.70$, $p = 0.002$] and a lower improvement in static strength [$B = -0.92$, $p < 0.001$] for the intervention group compared with the control group. The current lessons did not result in a significant change in executive functions.

INTRODUCTION

Reducing sedentary behavior and promoting regular participation in physical activity across the school day are essential goals to prevent chronic health conditions in children, including hypertension, insulin resistance and blood lipids (Bailey et al., 2012; Boddy et al., 2014). Emerging evidence has been collected showing that physical activity also has beneficial effects on cognitive performance in children (Donnelly & Lambourne, 2011; Tomporowski et al., 2015). Despite these benefits, Dutch children spend large amounts of their school-time (66%) in sedentary activities (van Stralen et al., 2014). Changing this pattern is difficult, given the concern in many primary schools over meeting the goals for academic achievement (Donnelly et al., 2013). An innovative strategy to reduce sedentary behavior and promote physical activity during school time is integrating physically active academic lessons into the curriculum (Norris et al., 2015). These types of educational lessons aim to incorporate physical activities with a moderate-to-vigorous intensity into the teaching of academic lesson content and do not come with the cost of academic instruction time.

Although research on the effects of physically active academic lessons is still in its infancy, it is already known that children that participate in moderate-to-vigorous physical activity (MVPA) regularly, improve their cardiovascular fitness (Kriemler et al., 2010; Kristensen et al., 2010). Considering the wide variety of physical exercises provided in physically active academic lessons, including lunges and squats, these lessons might also improve muscular fitness. This can result in additional physical health benefits, such as an improved bone health (Ortega et al., 2008; Smith et al., 2014).

The benefits of integrating physical activity into the curriculum might even extend beyond the physical health benefits. Emerging evidence indicates that physical activity is beneficial for academic achievement (Donnelly & Lambourne, 2011; Mullender-Wijnsma et al., 2015a) and executive functions (EF) in children (Best, 2010; Guiney & Machado, 2013; Sibley & Etnier, 2003; Verburgh et al., 2014). EF are those cognitive processes that are needed for complex, goal-oriented cognition and behavior (Welsh et al., 2006) and consists of at least three related domains: inhibition, which is the ability to avoid dominant or automatic responses and suppressing environmental interference; working memory, which involves temporarily keeping relevant information and further processing this information; and cognitive flexibility, which require children to switch between multiple tasks (Diamond et al., 2007; Miyake et al., 2000). Previous studies have shown that it is possible to improve EF in primary school children through a 9-month physical activity program, including at least 70 min of daily MVPA (Castelli et al., 2011; Hillman et al., 2014; Kamijo et al., 2011). The rationale for physical activity to improve EF in the long term is that regular participation in physical activity of moderate-to-vigorous intensity results in improvements in physical fitness (Kriemler et al., 2010; Kristensen et al., 2010), leading to several physiological changes. Physical activity is thought to enhance the angiogenesis and neurogenesis in areas of the brain that support memory and learning (Chaddock et al., 2011), which in turn can increase the perfusion capacity in the brain, subsequently enhancing EF (Querido & Sheel, 2007; Verburgh et al., 2014). For example, an increase in physical fitness is found to be associated with greater gray and white matter volume in the hippocampus and basal ganglia (Chaddock, Erickson, Prakash, VanPatter et al., 2010; Chaddock, Erickson, Prakash, Kim et al., 2010). To date, however, no studies have reported effects of physically active academic lessons on EF.

The aim of this study was to examine the effects of physically active academic lessons on cardiovascular fitness, muscular fitness and EF after 2 years. It was hypothesized that physically active academic lessons improve physical fitness and EF. This study is part of the project 'Fit en Vaardig op school' (Fit and academically proficient at school; F&V), a cluster-randomized controlled trial (RCT), in which primary school children were randomly assigned to a control group or a 22-week classroom-based intervention program. A relatively large pilot-study in six schools has shown that the F&V lessons can be successfully implemented in the curriculum and improve academic performance in third grade children (Mullender-Wijnsma et al., 2015a). Sub-analysis of the data collected in the first intervention year of the cluster-RCT showed an average MVPA engagement of 60% (Mullender-Wijnsma et al., 2015b).

METHODS

Participants and study design

Based upon the results of the physical activity across the curriculum (PAAC) study, an effect size of 0.44 was expected (J. E. Donnelly and J. L. Greene, personal communication) (Donnelly et al., 2009). Assuming an average class size of 25 children, power analysis [power = 0.80; α = 0.05; 1-tailed; Intraclass correlation = 0.10] resulted in a required sample size of 10 intervention classes and 10 control classes (Spybrook & Raudenbush, 2008). Twelve primary schools in the Northern part of the Netherlands participated in the 2-year intervention program. A second or third grade class from each school was randomly assigned to serve as an intervention group. All children from that class participated in the intervention program. The class that was not assigned to the intervention group was automatically classified as the control group. In total, data from 499 primary school children were obtained. The mean (SD) age of the study population was 8.1 (0.7) years and included 226 boys (45.3%) and 273 girls (54.7%). After randomization, 249 children were in the intervention group and 250 in the control group (Table 5.1). The control group consisted of a higher percentage of third grade children [$\chi^2(1) = 5.22$; p = 0.025] and was significantly older [$t(497) = 2.24$; $p = 0.026$] due to a difference in number of children within each class. No significant age differences were found when analyzing the second and third grade children separately. The intervention and control group were comparable on all other descriptive characteristics. In Figure 5.1 the number of participants are shown during each measurement period. Common reasons for not completing the tests were absence from school or leaving to attend another school. Due to circumstances not related to the intervention, two schools did not start the second intervention period, resulting in a lower sample size at T2 for both the control and intervention group. A loss of two schools was taken into account during the power analysis. Informed consent was obtained for all children and all procedures were approved by the institutional Ethics Committee of the Center for Human Movement Sciences of the University Medical Center Groningen, University of Groningen.

Table 5.1 Baseline demographics of the included study population.

	Intervention n = 249	Control n = 250	*p* value
Age, years (sd)	8.0 (0.7)	8.2 (0.7)	0.026[a]
Height, cm (sd)	131.9 (7.2)	132.5 (7.1)	0.371[a]
Weight, kg (sd)	29.9 (7.4)	29.9 (6.7)	0.971[a]
Grade, n third (%)	108 (43.4)	134 (53.6)	0.025[b]
Sex, n boys (%)	116 (46.6)	110 (44.0)	0.590[b]
BMI, kg/m^2 (sd)	17.0 (2.8)	16.9 (2.6)	0.577[a]
Overweight, n (%)[c]	40 (17.2)	43 (17.8)	0.616[b]
Obesity, n (%)[c]	20 (8.6)	15 (6.2)	

[a]Independent t-test. [b]Non-parametric Chi-square test. [c]According to the reference values by Cole et al. (2012).

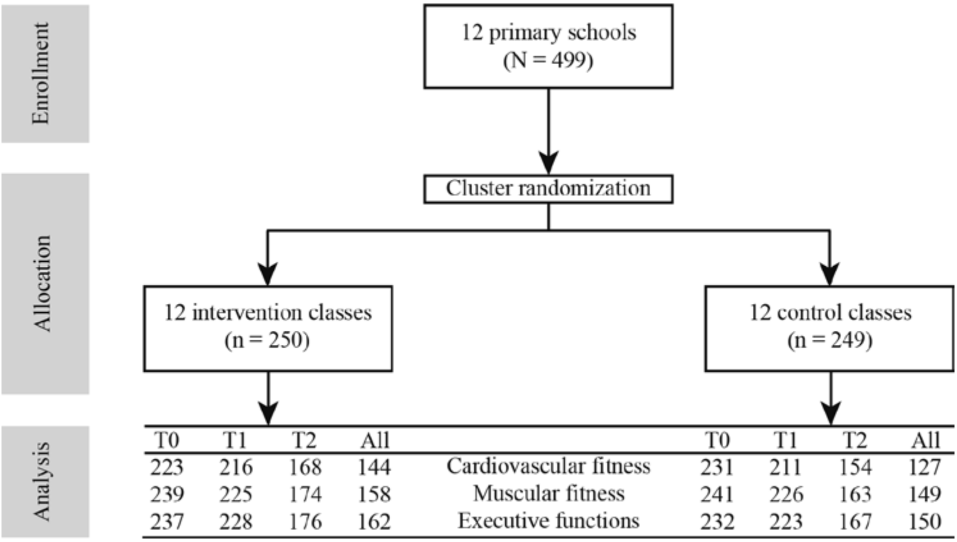


Figure 5.1 Flow chart showing the number of participants in each part of the study.

Measurements

Cardiovascular and muscular fitness

Physical fitness consists of at least two related domains: cardiovascular fitness, the capacity of the cardiovascular and respiratory system to perform continuous strenuous physical exercise; and muscular fitness, the capacity to perform work against a resistance (Ortega et al., 2008). The 10 × 5 m shuttle run (SR) (10 × 5 m SR, speed-coordination, in seconds) and the 20 m endurance SR (20 m SR, cardiorespiratory endurance, in number of completed stages) were administered for measuring cardiovascular fitness (de Greeff et al., 2014). Standing broad jump (SBJ, explosive strength, in cm), sit-ups in 30 s (SUP, muscular endurance, in number of completed SUP) and handgrip strength (HG, static strength, in kg) were administered for measuring muscular fitness (de Greeff et al., 2014). All tests were part of the standardized Eurofit test battery, which has been designed for the assessment of health-related fitness in both children as well as adults (Adam et al., 1988). Test-retest reliability [r between 0.62 and 0.97] and construct validity of all tests are adequate (van Mechelen et al., 1991).

Executive functions

The Golden Stroop test was used to measure inhibition (Strauss et al., 2006). In the first condition, children had to read aloud the words from a word card (color words printed in black ink). In the second (congruent) condition, children had to name the colors of colored rectangles from a color card (solid rectangles printed in red, green, yellow or blue ink). In the final (incongruent) condition, children had to name the color of the ink in which the words were written (color words printed in red, green, yellow or blue ink in which the ink does not match the word). For each card, the time was limited to 45 s and the score ranged from 0 to 100 correctly named words or colors. The Stroop interference score was calculated by subtracting the score of the incongruent condition from the score of the congruent condition (Strauss et al., 2006). The test re-test reliability [r = 0.81] indicate that the Stroop interference score has a good reliability within children (Neyens & Aldenkamp, 1997).

For working memory, the Digit span backward and Visual span backward were used (Wechsler, 1987). The Digit span backward involved presenting a sequence of spoken digits by the instructor followed by asking the child to recall the sequence in a reverse order. The number of digits in a sequence increased from two to eight. The test stopped when the child failed to recall at least two out of the three sequences within a span. The score ranged from 0 to 21 correctly recalled sequences. One practice trial was given to ensure that the child understood the test. The Visual span backward involved tapping a sequence of squares by the instructor on a card containing eight printed squares, followed by asking the child to tap the same squares in a reverse order. The number of tapped squares in a sequence increased from two to seven and the test stopped when the child fails to recall two sequences with the same length. The score was the total correctly tapped sequences and ranged from 0 to 12. Test re-test reliability for the Digit span backward [r = 0.82] and Visual span backward [r = 0.75] indicate that both tests are reliable (Wechsler, 1987). In addition, the factor loadings with general working memory indicate that both the Digit span backward [loading = 0.75] and the Visual memory span [loading = 0.65] are a valid measure for working memory (Wechsler, 1987).

Cognitive flexibility was measured using a modified version of the Wisconsin card sorting test (M-WCST), which is more suitable for children compared with the regular version (Cianchetti et al., 2007). The instructor placed four stimulus cards on a table in front of the child. Each stimulus card contained a unique shape (triangle, cross, circle or star), a unique color (yellow, red, green or blue) and a unique number of shapes (one, two, three or four). The child was instructed to sort the 48 response cards according to one of the unique characteristics. The child was told whether the card was sorted correctly or incorrectly. Only one sorting rule applied, after six consecutive correct responses the sorting rule changed and the instructor instructed the child to find another rule. The test stopped when all 48 cards were sorted, or when the child sorted the cards according to six different rules. A categorizing efficiency score was calculated (Cianchetti et al., 2007), meaning that for every correctly sorted rule six points were awarded and one point for each of the 48 cards not used.

Intervention program

The intervention program had a duration of 2 school years (2012–13 and 2013–14), 22 weeks per year (October until May), and consisted of three F&V lessons per week. The F&V lessons had a duration of 20–30 min, with 10–15 min spend on solving mathematical problems and 10–15 min spend on language. During the school holidays the lessons were not continued. Each F&V lesson was supported by a PowerPoint presentation and a manual describing the tasks in detail. In the first year, six primary school teachers were hired and trained to deliver the lessons. In the second year, the regular classroom teacher received a training in delivering F&V lessons and was made responsible for delivering the lessons. All F&V lessons were cognitively matched with the development of the children at each grade level. The physical activities were aimed to be of moderate-to-vigorous intensity. During the F&V lessons all children started with performing a basic exercise, such as jogging, hopping in place or marching. A specific exercise was performed when the children solved an academic task. For example, for mathematics, children had to jump eight times to solve the multiplication '4 × 2'. For language, children had to perform a squat for every spelled letter in the word 'dog'. After performing the specific exercise, children had to continue performing the basic exercise until the next academic task was shown. Heart rate monitoring results of the F&V lessons during the first intervention year of the cluster-RCT showed an average MVPA engagement of 60%, which can be translated in 14 min of MPVA per lesson (Mullender-Wijnsma et al., 2015b). A more detailed description of the intervention program and its implementation can be found elsewhere (Mullender-Wijnsma et al., 2015a; Mullender-Wijnsma et al., 2015b).

Procedure

In October 2012 (T0), EF were individually assessed in a quiet room at the school by instructed researchers. Approximately 2 weeks later, muscular and cardiovascular fitness were assessed during two regular physical education classes. Each instructed researcher received a 2 h training to get familiar with the EF and physical fitness tests and were mostly blinded to the condition children had been allocated to (during 88.6% of the measurements). The 12 intervention classes followed the intervention program directly after the baseline measurements, while the 12 control classes followed the regular lessons. In May 2013, 6 months after the start of the first intervention period (T1) and in May 2014 (directly after the second intervention period; T2), the children were tested using the same EF and physical fitness tests as was used during T0. During T1 and T2, assessments started with muscular and cardiovascular fitness to ensure that the physical fitness tests were administered as close to the start and end of the intervention program as possible.

Statistical analysis

Preliminary descriptive statistics were performed using SPSS for Windows (Version 22.0). Independent *t*-tests were performed on each test of cardiovascular fitness, muscular fitness and EF, comparing the scores of intervention group with the control group at T0, T1 and T2.

Multilevel regression analyses (MLwiN, version 2.29) were conducted for the main analysis. Multilevel analysis is particularly appropriate when using data with a nested source of variability, which is the case when studying children within multiple classes and schools (Snijders & Bosker, 2011). The outcome measures of the cardiovascular fitness tests (10 × 5 m and 20 m SR), muscular fitness tests (SBJ, SUP and HG) and the EF tests (Stroop test, Digit span, Visual span and M-WCST) at T2 were used as the dependent variables. For each dependent variable, three models were built in order to investigate the effects of the intervention on cardiovascular fitness, muscular fitness and EF. The covariates model contained only measurement period (categorical; T0, T1 and T2), grade and sex as fixed effects. Model 1 contained condition (intervention or control) as an additional fixed effect. Model 1 was used to investigate whether the intervention group differed from the control group after 2 years. Model 2 contained condition and the interaction between condition and measurement period (Condition × T1 and Condition × T2) as additional fixed effects. Model 2 was used to investigate whether the possible effects after 1 year were different from the effects after 2 years. For each model, school (level 3), child (level 2) and measurement period (level 1) were treated as random effects. The model fit was evaluated by comparing the deviance of the covariates model with the deviance of Model 1 and 2. Statistical significance was adopted for all tests when $p < 0.05$.

RESULTS

Descriptive statistics

Table 5.2 shows the results of the cardiovascular fitness, muscular fitness and EF outcomes at T0, T1 and T2. Children in the control group scored significantly higher on HG at T2 [$t(341) = 2.87$; $p = 0.004$] compared with the intervention group. For the 10 × 5 m SR, the intervention group performed significantly lower compared with the control group at T0 [$t(480) = -2.31$; $p = 0.021$) and at T1 [$t(453) = -2.55$; $p = 0.011$]. No significant differences between the control and intervention group were found for SBJ, SUP and the 20 m SR. Also, no significant differences were found for the tests of EF.

Effects on cardiovascular and muscular fitness

Table 5.3 shows the effects of the intervention (Model 2) on the tests of cardiovascular and muscular fitness. For HG, Model 2 significantly improved the model fit compared with the covariates model [$\Delta\chi^2(3) = 17.1$; $p < 0.001$]. T2 [$B = 3.26$; $p < 0.001$] and the interaction Condition × T2 were significant [$B = -0.92$; $p < 0.001$], indicating that HG has improved at T2, but the improvement for the intervention group [$B = 2.36$] was significantly smaller than the control group [$B = 3.26$]. No differences between the groups were found at T0 and T1. For the 10 × 5 m SR, Model 2 showed a significant improvement in model fit compared with the covariates model [$\Delta\chi^2(3) = 17.5$; $p < 0.001$]. A significant effect was found for T2 [$B = -0.85$; $p < 0.001$], Condition [$B = 0.65$; $p = 0.002$] and the interaction Condition × T2 [$B = -0.70$; $p = 0.002$]. This indicates that at T0, the intervention group [$B = 0.65$] was significantly slower than the control group. At T2, scores for the intervention group [$B = -0.90$] did not differ significantly from the control group [$B = -0.85$]. In other words, the intervention group demonstrated a larger improvement on the 10 × 5 m SR after 2 years, compared with the control group. As their performance at T0 was significantly lower, the intervention group did not score significantly higher at T2. For 20 m SR, SBJ and SUP, adding condition to the model (Model 1), or adding the interaction between condition and the intervention period (Model 2) did not significantly improve the covariates model.

Effects on EF

For EF, neither adding condition to the model (Model 1), nor adding the interactions between condition and intervention period (Model 2) did significantly improve the covariates model for any of the tests (Table 5.4). This indicates that there were no differences between the intervention and control group during T0, T1 and T2.

Table 5.2 Mean scores on the domains of cardiovascular fitness, muscular fitness and executive functions at T0, T1 and T2, separated for the intervention and control group.

		Intervention n = 249	Control n = 250
Cardiovascular fitness			
10x5m shuttle run, s	T0	24.8 (2.6)*	24.3 (2.7)*
	T1	25.0 (2.4)*	24.4 (2.6)*
	T2	23.3 (2.3)	23.4 (2.6)
20m shuttle run, stage	T0	3.9 (1.7)	4.1 (2.0)
	T1	4.3 (1.8)	4.2 (2.0)
	T2	4.7 (2.0)	4.9 (2.2)
Muscular fitness			
Standing broad jump, cm	T0	123.0 (20.1)	125.5 (21.3)
	T1	124.1 (18.8)	123.5 (19.5)
	T2	129.7 (21.4)	131.2 (19.9)
Sit-ups, n	T0	15.1 (3.9)	15.4 (4.2)
	T1	16.4 (4.7)	16.3 (4.8)
	T2	16.7 (4.9)	17.2 (4.7)
Handgrip strength, kg	T0	13.3 (3.3)	13.5 (3.3)
	T1	14.9 (3.7)	15.0 (3.5)
	T2	15.8 (3.7)**	17.0 (3.8)**
Executive functions			
Stroop	T0	17.9 (7.9)	17.5 (8.1)
	T1	18.4 (8.1)	19.0 (7.5)
	T2	19.6 (8.1)	19.9 (9.5)
Digit span backward	T0	5.1 (1.7)	5.0 (1.5)
	T1	5.6 (1.7)	5.6 (1.7)
	T2	6.0 (2.2)	6.2 (1.9)
Visual span backward	T0	5.6 (1.9)	5.7 (1.8)
	T1	6.5 (1.7)	6.7 (1.7)
	T2	6.6 (1.7)	6.8 (1.6)
M-WCST	T0	20.8 (11.4)	21.7 (11.8)
	T1	26.8 (12.1)	28.0 (12.5)
	T2	31.6 (10.8)	30.3 (11.3)

Values are mean (SD).
M-WCST = modified Wisconsin card sorting test.
*Significant differences between control and intervention group with $p < 0.05$;**Significantly different at $p < 0.01$.

Table 5.3 Results of the multilevel analyses for cardiovascular and muscular fitness (Model 2).

	Cardiovascular fitness		Muscular fitness		
	10x5m SR	20m SR	SBJ	SUP	HG
Fixed effects (SE)					
Intercept	25.00 (0.31), $p < 0.001$	3.44 (0.21), $p < 0.001$	117.21 (1.62), $p < 0.001$	14.17 (0.41), $p < 0.001$	11.90 (0.28), $p < 0.001$
Grade[a]	-0.96 (0.18), $p < 0.001$	0.24 (0.14), $p = 0.095$	9.18 (1.52), $p < 0.001$	1.45 (0.34), $p < 0.001$	2.49 (0.27), $p < 0.001$
Sex[b]	-0.89 (0.18), $p < 0.001$	1.14 (0.14), $p < 0.001$	7.95 (1.52), $p < 0.001$	1.00 (0.34), $p = 0.003$	0.69 (0.27), $p = 0.012$
T1	0.16 (0.15), $p = 0.265$	0.19 (0.11), $p = 0.078$	-2.36 (1.12), $p = 0.035$	0.92 (0.28), $p < 0.001$	1.56 (0.16), $p < 0.001$
T2	-0.85 (0.17), $p < 0.001$	0.87 (0.12), $p < 0.001$	4.56 (1.26), $p < 0.001$	1.73 (0.31), $p < 0.001$	3.26 (0.17), $p < .001$
Condition[c]	**0.65 (0.21), $p = 0.002$**	-0.08 (0.16), $p = 0.613$	-1.86 (1.74), $p = 0.283$	-0.16 (0.40), $p = 0.685$	0.02 (0.30), $p = 0.954$
Condition*T1	-0.05 (0.21), $p = 0.804$	0.12 (0.15), $p = 0.305$	3.29 (1.58), $p = 0.038$	0.33 (0.39), $p = 0.402$	-0.05 (0.22), $p = 0.806$
Condition*T2	**-0.70 (0.23), $p = 0.002$**	-0.25 (0.17), $p = 0.138$	2.16 (1.76), $p = 0.220$	-0.33 (0.43), $p = 0.450$	**-0.92 (0.24), $p < 0.001$**
Model summary					
Deviance statistics	5446.6	4594.4	10710.5	7034.8	5949.7
Number of estimated parameters	11	11	11	11	11

Significant effects related to the hypotheses are shown in bold font.
10 × 5 m SR = 10 × 5 m shuttle run, 20 m SR = 20 m endurance shuttle run, SBJ = standing broad jump, SUP = sit-ups, HG = handgrip strength.
[a,b,c]Respectively second grade, girls and control group are coded as 0. Third grade, boys and intervention group are coded as 1.

Table 5.4 Results of the multilevel analyses for executive functions (Model 2).

	Stroop	Digit span	Visual span	M-WCST
Fixed effects (SE)				
Intercept	16.40 (0.64), $p < 0.001$	4.60 (0.14), $p < 0.001$	5.21 (0.15), $p < 0.001$	19.54 (0.99), $p < 0.001$
Grade[a]	1.57 (0.54), $p = 0.004$	0.76 (0.12), $p < 0.001$	0.63 (0.12), $p < 0.001$	5.13 (0.85), $p < 0.001$
Sex[b]	0.61 (0.54), $p = 0.259$	-0.04 (0.12), $p = 0.751$	0.34 (0.12), $p = 0.005$	-1.39 (0.85), $p = 0.102$
T1	1.52 (0.65), $p = 0.020$	0.58 (0.13), $p < 0.001$	0.96 (0.13), $p < 0.001$	6.26 (0.78), $p < 0.001$
T2	2.28 (0.72), $p = 0.002$	1.12 (0.14), $p < 0.001$	1.07 (0.14), $p < 0.001$	9.11 (0.87), $p < 0.001$
Condition[c]	0.57 (0.74), $p = 0.443$	0.14 (0.16), $p = 0.383$	-0.05 (0.16), $p = 0.767$	-0.42 (1.04), $p = 0.685$
Condition*T1	-1.06 (0.92), $p = 0.250$	-0.06 (0.18), $p = 0.732$	-0.08 (0.18), $p = 0.672$	-0.09 (1.09), $p = 0.937$
Condition*T2	-0.83 (1.01), $p = 0.408$	-0.27 (0.20), $p = 0.171$	-0.14 (0.20), $p = 0.469$	1.55 (1.21), $p = 0.200$
Model summary				
Deviance statistics	9035.5	4981.9	4966.2	9760.3
Number of estimated parameters	11	11	11	11

M-WCST = Modified Wisconsin card sorting test.
[a,b,c]Respectively second grade, girls and control group are coded as 0. Third grade, boys and intervention group are coded as 1.

DISCUSSION

The aim of this study was to examine the effects of physically active academic lessons on cardiovascular fitness, muscular fitness and EF after 2 years. The results showed that, for cardiovascular fitness, a larger improvement in speed-coordination (assessed with the 10 × 5 m SR) was found in the intervention group, compared with the control group. For muscular fitness, a smaller improvement in static strength (assessed with HG) was found in the intervention group compared with the control group. For EF, no significant differences were found between the control and intervention group after 1 or 2 years.

Although the intervention group had significantly lower baseline scores, the increase in speed-coordination after 2 intervention years was larger for the intervention group compared with the control group. This larger increase for the intervention group could be due to the short intermitted nature of most of the physical activities during the physically active academic lessons. For example, the children had to spell a word by jumping in place for every mentioned letter. After spelling the word, children had to switch to jogging in place until the next word was shown. The intervention program did not result in an improvement of cardiorespiratory endurance (assessed with the 20 m SR) after 2 intervention years. A previous study has shown that a 9-month physical activity program, which provided first and fifth graders about 13 min of additional in-school MVPA on a daily basis, resulted in a significant improvement of cardiovascular fitness (Kriemler et al., 2010). The children in this study engaged in similar amounts of MVPA per lesson, but the lessons were provided three times a week instead of daily. It is possible that the frequency of the physically active academic lessons was not enough to positively affect the scores of both tests measuring cardiovascular fitness. Several other studies recommended at least 30 min of daily MVPA to improve cardiovascular fitness in school-aged children (Hillman et al., 2014; Janssen & LeBlanc, 2010; Kamijo et al., 2011). We therefore hypothesize that future studies may need to focus on interventions programs that provide MPVA on a daily basis in order to positively affect cardiovascular fitness.

It is widely assumed that physical activity has a positive effect on EF in children (Best, 2010; Guiney & Machado, 2013; Sibley & Etnier, 2003; Tomporowski et al., 2015; Verburgh et al., 2014). A recent meta-analysis, investigating the effects of physical activity on EF, showed a moderate positive effect size for studies that measured EF directly (within minutes or hours) after a single short-term exercise bout [d = 0.57] (Verburgh et al., 2014). However, as a result of insufficient studies with a high-quality design, it is difficult to make conclusions about the effect of long-term physical activity interventions on EF (Chaddock et al., 2011; Guiney & Machado, 2013). This study showed that the children did not significantly improve on the four tests representing EF after 2 years. In contrast, a 9-month after-school physical activity program (FIT Kids program), including at least 70 min of MVPA per day, resulted in improvements in working memory (Hillman et al., 2014; Kamijo et al., 2011), inhibition and cognitive flexibility (Hillman et al., 2014). In addition, children participating in the FIT kids program improved their cardiovascular fitness (Hillman et al., 2014). A possible explanation for these conflicting results is that the effect of physical activity on EF could partly be mediated by cardiovascular fitness.

The cardiovascular fitness hypothesis states that changes in cardiovascular fitness, as a result of regular MVPA, leads to physiological changes in the brain structural network (Etnier et al., 2006). Examples of these physiological changes are an elevated cerebral blood flow and an increased concentration level of growth factors responsible for neurogenesis and the synaptic plasticity of the brain (Dishman et al., 2006; Hillman et al., 2008). The current intervention program, in contrast with the FIT Kids program, was unable to improve cardiovascular fitness, which might partly explain the lack of significant effects in the present study. However, more research on the mediating role of cardiovascular fitness in this age group needs to be undertaken before the effects of physical activity on EF is clearly understood.

Some limitations should be considered for future research. First, despite randomly assigning the classes to either the control or intervention group, age and the number of second and third graders differed at baseline. As no age differences were found when analyzing the second and third grade children separately, the significant differences in grade likely resulted in the significant age difference. To control for these differences, grade was added as a control variable in the multilevel models. In addition, the intervention group performed lower on speed-coordination at baseline, compared with the control group. Although we controlled for differences at baseline in the multilevel models, the results need to be interpreted with caution. Second, it remains unclear whether or not physically active academic lessons affected the physical activity during out-of-school time. According to the ‘activitystat hypothesis’, children compensate the increased physical activity during one part of the day by a decrease in physical activity during another part of the day in order to maintain a particular physical activity set point (Ridgers et al., 2014; Rowland, 1998). It is therefore possible that the children in the intervention group were less active during out-of-school time because of the increase in physical activity during in-school time. Future intervention studies should therefore measure the time spend in out-of-school and in-school MVPA. Last, in the second intervention year the regular classroom teacher delivered the intervention instead of the hired teacher. Although the effects of the first intervention year did not differ from the second intervention year, this change in teacher could have confounded the efficacy of the delivery of the intervention. Strengths of this study were the RCT design and the large sample size.

In conclusion, our program provided a unique approach as it integrated physical activity into the teaching of academic lesson content. This study is, according to the authors knowledge, the first to report long-term effects of physically active academic lessons on cardiovascular fitness, muscular fitness and/or EF. Effects on cardiovascular and muscular fitness were small, but the intervention program resulted in an improvement in speed-coordination. The current lessons did not result in a significant change in EF. These results again highlight the difficulty to positively influence some of the health and cognitive aspects in primary school children. Our findings nevertheless provide important practical considerations for future studies that focus on physically active academic lessons.

REFERENCES

Adam, C., et al. (1988). *EUROFIT: European test of physical fitness*. Rome: Council of Europe, Committee for the Development of Sport.

Bailey, D. P., Boddy, L. M., Savory, L. A., Denton, S. J., & Kerr, C. J. (2012). Associations between cardiorespiratory fitness, physical activity and clustered cardiometabolic risk in children and adolescents: The HAPPY study. *European Journal of Pediatrics, 171*(9), 1317-1323.

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review, 30*(4), 331-351.

Boddy, L. M., Murphy, M. H., Cunningham, C., Breslin, G., Foweather, L., Gobbi, R., et al. (2014). Physical activity, cardiorespiratory fitness, and clustered cardiometabolic risk in 10- to 12-year-old school children: The REACH Y6 study. *American Journal of Human Biology : The Official Journal of the Human Biology Council, 26*(4), 446-451.

Castelli, D. M., Hillman, C. H., Hirsch, J., Hirsch, A., & Drollette, E. (2011). FIT kids: Time in target heart zone and cognitive performance. *Preventive Medicine, 52*, S55-S59.

Chaddock, L., Erickson, K. I., Prakash, R. S., Kim, J. S., Voss, M. W., VanPatter, M., et al. (2010). A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. *Brain Research, 1358*, 172-183.

Chaddock, L., Erickson, K. I., Prakash, R. S., VanPatter, M., Voss, M. W., Pontifex, M. B., et al. (2010). Basal ganglia volume is associated with aerobic fitness in preadolescent children. *Developmental Neuroscience, 32*(3), 249-256.

Chaddock, L., Pontifex, M. B., Hillman, C. H., & Kramer, A. F. (2011). A review of the relation of aerobic fitness and physical activity to brain structure and function in children. *Journal of the International Neuropsychological Society, 17*(06), 975-985.

Cianchetti, C., Corona, S., Foscoliano, M., Contu, D., & Sannio-Fancello, G. (2007). Modified Wisconsin card sorting test (MCST, MWCST): Normative data in children 4–13 years old, according to classical and new types of scoring. *The Clinical Neuropsychologist, 21*(3), 456-478.

Cole, T., & Lobstein, T. (2012). Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatric Obesity, 7*(4), 284-294.

De Greeff, J. W., Hartman, E., Mullender-Wijnsma, M. J., Bosker, R. J., Doolaard, S., & Visscher, C. (2014). Physical fitness and academic performance in primary school children with and without a social disadvantage. *Health Education Research, 29*(5), 853-860.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science, 318*(5855), 1387-1388.

Dishman, R. K., Berthoud, H., Booth, F. W., Cotman, C. W., Edgerton, V. R., Fleshner, M. R., et al. (2006). Neurobiology of exercise. *Obesity, 14*(3), 345-356.

Donnelly, J. E., Greene, J., Gibson, C. A., Sullivan, D. K., Hansen, D. M., Hillman, C. H., et al. (2013). Physical activity and academic achievement across the curriculum (A + PAAC): Rationale and design of a 3-year, cluster-randomized trial. *BMC Public Health, 13*, 307.

Donnelly, J. E., & Lambourne, K. (2011). Classroom-based physical activity, cognition, and academic achievement. *Preventive Medicine, 52*, S36-S42.

Donnelly, J. E., Greene, J. L., Gibson, C. A., Smith, B. K., Washburn, R. A., Sullivan, D. K., et al. (2009). Physical activity across the curriculum (PAAC): A randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. *Preventive Medicine, 49*(4), 336-341.

Etnier, J. L., Nowell, P. M., Landers, D. M., & Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews, 52*(1), 119-130.

Guiney, H., & Machado, L. (2013). Benefits of regular aerobic exercise for executive functioning in healthy populations. *Psychonomic Bulletin & Review, 20*(1), 73-86.

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9*(1), 58-65.

Hillman, C. H., Pontifex, M. B., Castelli, D. M., Khan, N., Raine, L., Scudder, M., et al. (2014). Effects of the FITKids randomized controlled trial on executive control and brain function. *Pediatrics, 134*(4), e1063-e1071.

Janssen, I., & LeBlanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity, 7*(40), 1-16.

Kamijo, K., Pontifex, M. B., O'Leary, K. C., Scudder, M. R., Wu, C., Castelli, D. M., et al. (2011). The effects of an afterschool physical activity program on working memory in preadolescent children. *Developmental Science, 14*(5), 1046-1058.

Kriemler, S., Zahner, L., Schindler, C., Meyer, U., Hartmann, T., Hebestreit, H., et al. (2010). Effect of school based physical activity programme (KISS) on fitness and adiposity in primary schoolchildren: Cluster randomised controlled trial. *BMJ, 340*, c785.

Kristensen, P. L., Moeller, N. C., Korsholm, L., Kolle, E., Wedderkopp, N., Froberg, K., et al. (2010). The association between aerobic fitness and physical activity in children and adolescents: The European Youth Heart Study. *European Journal of Applied Physiology, 110*(2), 267-275.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100.

Mullender-Wijnsma, M. J., Hartman, E., de Greeff, J. W., Bosker, R. J., Doolaard, S., & Visscher, C. (2015a). Improving academic performance of school-age children by physical activity in the classroom: Year one program evaluation. *Journal of School Health, 85*(6), 365-371.

Mullender-Wijnsma, M. J., Hartman, E., de Greeff, J. W., Bosker, R. J., Doolaard, S., & Visscher, C. (2015b). Moderate-to-vigorous physically active academic lessons and academic engagement in children with and without a social disadvantage: A within subject experimental design. *BMC Public Health, 15*(1), 404.

Neyens, L. G., & Aldenkamp, A. P. (1997). Stability of cognitive measures in children of average ability. *Child Neuropsychology, 3*(3), 161-170.

Norris, E., Shelton, N., Dunsmuir, S., Duke-Williams, O., & Stamatakis, E. (2015). Physically active lessons as physical activity and educational interventions: A systematic review of methods and results. *Preventive Medicine, 72*, 116-125.

Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity, 32*(1), 1-11.

Querido, J. S., & Sheel, A. W. (2007). Regulation of cerebral blood flow during exercise. *Sports Medicine, 37*(9), 765-782.

Ridgers, N. D., Timperio, A., Cerin, E., & Salmon, J. (2014). Compensation of physical activity and sedentary time in primary school children. *Medicine and Science in Sports and Exercise, 46*(8), 1564-1569.

Rowland, T. W. (1998). The biological basis of physical activity. *Medicine and Science in Sports and Exercise, 30*(3), 392-399.

Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: A meta-analysis. *Pediatric Exercise Science, 15*(3), 243-256.

Smith, J. J., Eather, N., Morgan, P. J., Plotnikoff, R. C., Faigenbaum, A. D., & Lubans, D. R. (2014). The health benefits of muscular fitness for children and adolescents: A systematic review and meta-analysis. *Sports Medicine, 44*(9), 1209-1223.

Snijders, T., & Bosker, R. (2011). *Multilevel analysis: An introduction to basic and advanced multilevel modeling*. London: Sage Publications Limited.

Spybrook, J., & Raudenbush, S. W. (2008). *Optimal design software [computer software].* Michigan: University of Michigan.

Strauss, E. H., et al. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary*. New York: Oxford University Press.

Tomporowski, P. D., McCullick, B., Pendleton, D. M., & Pesce, C. (2015). Exercise and children's cognition: The role of exercise characteristics and a place for metacognition. *Journal of Sport and Health Science, 4*(1), 47-55.

Van Mechelen, W., et al. (1991). *Eurofit: Handleiding met referentieschalen voor 12- tot en met 16-jarige jongens en meisjes in Nederland (manual with referencevalues for 12-16 year old boys and girls in the Netherlands)*. Haarlem: De Vrieseborch.

van Stralen, M. M., Yıldırım, M., Wulp, A., te Velde, S. J., Verloigne, M., Doessegger, A., et al. (2014). Measured sedentary time and physical activity during the school day of European 10- to 12-year-old children: The ENERGY project. *Journal of Science and Medicine in Sport, 17*(2), 201-206.

Verburgh, L., Königs, M., Scherder, E. J., & Oosterlaan, J. (2014). Physical exercise and executive functions in preadolescent children, adolescents and young adults: A meta-analysis. *British Journal of Sports Medicine, 48*(12), 973-979.

Wechsler, D. (1987). *WMS-R: Wechsler memory scale-revised: Manual.* San Antonio: Psychological Corporation.

Welsh, M. C., et al. (2006). Executive functions in developing children: Current conceptualizations and questions for the future. In K. McCartney, & D. Philips (Eds.), *The Blackwell handbook of early childhood development.* (pp. 167-187). Oxford: Blackwell Publishing Ltd.

CHAPTER 6

Summary & general discussion

SUMMARY OF THE MAIN FINDINGS

In Chapter 1 we hypothesized that physical fitness is a mediator between socioeconomic status (SES) and cognition (executive functions and academic performance). Physical fitness can only be considered a mediator when all relations between SES, physical fitness and cognition are significantly related with each other. Therefore, we started the research of the current thesis by first investigating the relationships between physical fitness, executive functions and academic performance in both socially disadvantaged children (SDC) and children without this disadvantage (non-SDC). The second purpose and the main aim of the current research, was to investigate the effects of physically active academic lessons on physical fitness and executive functions.

Chapter 2 showed that SDC scored significantly lower on academic performance compared with non-SDC. Secondly, Chapter 2 showed that SDC and non-SDC did not differ on physical fitness and that within both SDC and non-SDC, cardiovascular fitness was positively related with mathematics. For spelling, the relationship with cardiovascular fitness was only found in non-SDC and not in SDC. In Chapter 3 the two main findings were that SDC scored lower than non-SDC on one of the domains of executive functions (cognitive flexibility) and that cardiovascular fitness was related with cognitive flexibility. The findings in Chapter 2 and 3 therefore indicate that SDC scored lower than non-SDC on cognitive flexibility and academic performance. SDC did not differ from non-SDC on physical fitness and therefore physical fitness is not a mediator between SES and cognition. Chapter 2 and 3 also indicate that physical fitness was related with multiple domains of cognition. From these findings we cannot confirm any type of causality, however, increasing cardiovascular fitness in both SDC as well as non-SDC might be beneficial for mathematics or cognitive tasks that require cognitive flexibility.

During this thesis, a 2-year classroom-based intervention program was developed that focuses on integrating physical activity into the routine academic lessons such as mathematics, spelling and reading ('Fit en Vaardig op school'). In Chapter 4 and 5 the effects of these physically active academic lessons on BMI, physical fitness and executive functions are investigated. The two main findings from Chapter 4 are that after one intervention year, the lessons had no effects on cardiovascular or muscular fitness and a positive effect on BMI in third grade children. In this subgroup, BMI of the intervention group did not change, whereas BMI in the control group increased significantly. The main findings from Chapter 5 were that after two intervention years, the lessons had a positive effect on speed-coordination and a negative effect on static strength. The lessons had no effect on executive functions.

Relationships between physical fitness, executive functions and academic performance in SDC and non-SDC

The current thesis shows that cardiovascular fitness was related with a specific domain of executive functions (cognitive flexibility) and with multiple domains of academic performance (mathematics and spelling). These findings complement the results of previous studies which shows that improvements in cardiovascular fitness co-occur with improvements in the brain structural network responsible for learning, such as increased white matter in the hippocampus (Chaddock, Erickson, Prakash, Kim et al., 2010) and the basal ganglia (Chaddock, Erickson, Prakash, VanPatter, et al., 2010). These findings also provide some support for the cardiovascular fitness hypothesis (Etnier et al., 2006), which states that by being physically active regularly, cardiovascular fitness will improve which results in improvements in cognition. It is hypothesized that by being physically active regularly, cerebral blood flow increases and, in the long term, structural changes of the brain structural network occur which will result in cognitive improvements (Etnier et al., 2006). However, these cross-sectional relationships did not provide insight into the causality and further research is needed to support this hypothesis. It did however provide a good argument for starting a randomized controlled trial which investigates the effects of physical activity on cognition.

One of the additional questions in Chapter 2 and 3 was whether or not differences could be found between SDC and non-SDC in physical fitness, executive functions and academic performance. Previous literature has shown that SDC are at risk for low physical fitness levels (Duncan et al., 1994; Poulton et al., 2002) and score low on executive functions (Ardila et al., 2005; Waber et al., 2006) and academic performance (Chomitz et al., 2008; Sirin, 2005). It was therefore hypothesized that SDC scored lower on physical fitness, executive functions and academic performance compared with non-SDC. Assuming that physical fitness is related with cognition, it was also hypothesized that a low physical fitness in SDC might partly explain their lower scores on executive functions and their low academic performance. The results in Chapter 2 confirmed that SDC scored lower on all domains of academic performance (mathematics, spelling and reading) and the results in Chapter 3 confirmed that SDC scored lower on one of the domains of executive functions (cognitive flexibility). However, SDC did not score lower on physical fitness. These results indicate that the lower academic performance cannot be partly explained by physical fitness and physical fitness is therefore not a mediator between SES and cognition.

Effects of physically active academic lessons on physical fitness and executive functions

A 2-year classroom-based intervention program was developed that focuses on integrating physical activity into the routine academic lessons such as mathematics, spelling and reading ('Fit en Vaardig op school'). The children in the intervention group participated in three physically active academic lessons per week with a duration of 20-30 minutes per lesson. After two intervention years (22 weeks per year), only small or no significant effects were found on physical fitness and executive functions. In addition, Chapter 4 showed that there we no differential responses by initial level of physical fitness. This indicates that there were also no effects on physical fitness or executive functions for the children with initial lower levels of physical fitness. Based on previous studies, larger effects on physical fitness and executive functions were expected. For example, a 9-month after-school physical activity program (FIT Kids program), including at least 60 min of MVPA per day, resulted in improvements in working memory (Hillman et al., 2011; Kamijo et al., 2011), inhibition and cognitive flexibility (Hillman et al., 2011). Furthermore, the FIT Kids program also resulted in improved cardiovascular fitness (Kamijo et al., 2011). As was explained in Chapter 1, it was assumed that regular MVPA increases physical fitness which in turn leads to cognitive improvements. The fact that the physically active academic lessons did not result in improvements in physical fitness might explain the lack of significant improvements in executive functions.

It is known that increasing physical fitness in preadolescent children can be challenging, because it is determined for a large part by other factors such as genetic factors. It is possible that the children already scored relatively high on physical fitness, making it difficult to improve it even further. However, in Chapter 2 the performance on physical fitness was compared with a relative large sample of 8-year-old Latvian children (Sauka et al., 2011), which showed that both SDC and non-SDC in the current research had lower cardiovascular and muscular fitness scores. In addition, Chapter 4 has shown that for children with initially lower levels of physical fitness or children with initially higher BMI no effects were found on physical fitness. An alternative explanation can be found when looking at the (internal) exercise load of the lessons which was objectively measured during the first intervention year with heart rate monitors. Although the differences in mean heart rate between children was large, heart rate monitoring results showed an average estimated MVPA engagement of 60%, which can be translated in 14 minutes of MVPA per lesson (Mullender-Wijnsma et al., 2015). It can be argued that an intervention program that provides an average of 14 minutes of extra in-school MVPA, three times a week, is not enough to improve physical fitness in this age range.

Conclusions and future recommendations

Research on integrating physical activity into academic lessons is in its infancy and the true potential has yet to be fully understood, but it has undoubtedly important potential value in the school curriculum. This research has shown that it is possible to implement physical activity into the classroom without the cost of academic instruction time. The current lessons provide primary school teachers a novel strategy to integrate physical activity into the regular academic lessons. By integrating physical activity into the academic content children were challenged and motivated throughout the schoolyear. After one intervention year, the lessons had a positive effect on BMI in third grade children. The lessons had small or no effects on physical fitness and no effect on executive functions. Despite these limited findings, the major strengths of the 'Fit en Vaardig op school'-project was that it used a cluster randomized controlled study design, a large sample size and a relative long intervention period, making it possible to draw strong conclusions from the data.

The findings in the current thesis have also provided us some important suggestions for future directions. First, one of the challenges in this line of research is the difficulty in measuring executive functions in typically developing children. Although the tests are reliable and valid for preadolescent children (for details see method section in Chapter 3), the tests are originally developed for detecting deficiencies in a normal child's brain (Pennington & Ozonoff, 1996). It is unknown how suitable the tests are in measuring changes over time in preadolescent children without deficiencies. Chapter 5 showed that grade was a significant predictor for the scores on all of the tests for executive functions, indicating that third grade children scored significantly higher on all tests compared with second grade children. It is therefore likely that the tests are sensitive enough to detect developments in executive functions after one schoolyear. It is possible that a smaller but still relevant increase in performance cannot be detected by the tests used in the current thesis.

Second, the finding that physically active academic lessons did not improve physical fitness highlight the difficulty to positively influence physical fitness in primary school children. Recently, an increasing number of studies are beginning to question whether it is crucial to increase physical fitness in order to achieve cognitive benefits (Koutsandreou, 2016; Pesce, 2013). It is possible that the cognitive demands of physical activity moderate the effect of physical activity on cognitive functions. This indicates that physical activity programs with a high cognitive engagement (e.g. motor coordination or complex coordinative exercises), rather than low cognitive engagement (e.g. repetitive and nonadaptive exercises) might enhance cognitive performance. Future research should therefore not only focus on the quantitative characteristics of physical activity (i.e. dose-response relations between physical activity and cognitive performance), but also on the qualitative characteristics of physical activity (i.e. type of physical activity) (Pesce, 2012). To further understand the effects of physical activity on cognition in primary school children, we will therefore examine the effects of two intervention programs with different cognitive demands (aerobic exercise versus coordinative exercise) on cognitive performance.

REFERENCES

Ardila, A., Rosselli, M., Matute, E., & Guajardo, S. (2005). The influence of the parents' educational level on the development of executive functions. *Developmental Neuropsychology, 28*(1), 539-560.

Chaddock, L., Erickson, K. I., Prakash, R. S., Kim, J. S., Voss, M. W., VanPatter, M., et al. (2010). A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. *Brain Research, 1358*, 172-183.

Chaddock, L., Erickson, K. I., Prakash, R. S., VanPatter, M., Voss, M. W., Pontifex, M. B., et al. (2010). Basal ganglia volume is associated with aerobic fitness in preadolescent children. *Developmental Neuroscience, 32*(3), 249-256.

Chomitz, V. R., Slining, M. M., McGowan, R. J., Mitchell, S. E., Dawson, G. F., & Hacker, K. A. (2008). Is there a relationship between physical fitness and academic achievement? positive results from public school children in the Northeastern United States. *Journal of School Health, 79*(1), 30-37.

Duncan, G. J., Brooks-Gunn, J., & Klebanov, P. K. (1994). Economic deprivation and early childhood development. *Child Development, 65*(2), 296-318.

Etnier, J. L., Nowell, P. M., Landers, D. M., & Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews, 52*(1), 119-130.

Hillman, C. H., Kamijo, K., & Scudder, M. (2011). A review of chronic and acute physical activity participation on neuroelectric measures of brain health and cognition during childhood. *Preventive Medicine, 52*, S21-S28.

Kamijo, K., Pontifex, M. B., O'Leary, K. C., Scudder, M. R., Wu, C., Castelli, D. M., et al. (2011). The effects of an afterschool physical activity program on working memory in preadolescent children. *Developmental Science, 14*(5), 1046-1058.

Mullender-Wijnsma, M. J., Hartman, E., de Greeff, J. W., Bosker, R. J., Doolaard, S., & Visscher, C. (2015). Moderate-to-vigorous physically active academic lessons and academic engagement in children with and without a social disadvantage: A within subject experimental design. *BMC Public Health, 15*(1), 404.

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry, 37*(1), 51-87.

Pesce, C. (2012). Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *Journal of Sport and Exercise Psychology, 34*(6), 766-786.

Poulton, R., Caspi, A., Milne, B. J., Thomson, W. M., Taylor, A., Sears, M. R., et al. (2002). Association between children's experience of socioeconomic disadvantage and adult health: A life-course study. *The Lancet, 360*(9346), 1640-1645.

Sauka, M., Priedite, I. S., Artjuhova, L., Larins, V., Selga, G., Dahlström, Ö, et al. (2011). Physical fitness in Northern European youth: Reference values from the Latvian physical health in youth study. *Scandinavian Journal of Public Health, 39*(1), 35-43.

Sirin, S. R. (2005). Socioeconomic status and academic achievement: A meta-analytic review of research. *Review of Educational Research, 75*(3), 417-453.

Slingerland, M., Oomen, J., & Borghouts, L. (2011). Physical activity levels during Dutch primary and secondary school physical education. *European Journal of Sport Science, 11*(4), 249-257.

Waber, D. P., Gerber, E. B., Turcios, V. Y., Wagner, E. R., & Forbes, P. W. (2006). Executive functions and performance on high-stakes testing in children from urban schools. *Developmental Neuropsychology, 29*(3), 459-477.

APPENDICES

NEDERLANDSE SAMENVATTING

Het is al bekend dat wanneer kinderen regelmatig matig tot intensief bewegen het risico op negatieve gezondheidseffecten zal afnemen (bijvoorbeeld hart- en vaatziekten). Daarom adviseert de Wereldgezondheidsorganisatie (Engels: World Health Organization, WHO) kinderen om per dag 60 minuten te besteden aan matig tot intensieve fysieke activiteit. Het aantal Nederlandse kinderen dat de dagelijkse norm van een uur bewegen haalt is in de periode van 2000 tot 2014 echter afgenomen, terwijl de tijd die kinderen spenderen aan fysieke inactiviteit is toegenomen. Aangezien een fysiek inactieve levensstijl tijdens de basisschoolperiode een belangrijke voorspeller is voor een inactieve levensstijl op volwassen leeftijd, is het noodzakelijk om al tijdens de basisschoolperiode effectieve strategieën te implementeren die de mate van fysieke activiteit verhogen.

Er is ook steeds meer bewijs dat regelmatig matig tot intensief bewegen de cognitieve functies kan verbeteren, met name de executieve functies. Executieve functies zijn cognitieve processen die het mogelijk maken dat een kind doelgericht bezig is en bestaan in dit proefschrift uit drie gerelateerde componenten: Inhibitie, werkgeheugen en cognitieve flexibiliteit. Uit eerder onderzoek is al gebleken dat executieve functies een belangrijke voorwaarde vormen voor het leerproces van kinderen en dat er een sterke positieve relatie is tussen executieve functies en schoolprestaties. Schoolprestaties worden in dit proefschrift gedefinieerd als prestaties op vaardigheden die op de basisschool geleerd worden en bestaan in dit proefschrift uit drie onderdelen: rekenen, spelling en lezen. De hypothese is dat regelmatig matig tot intensief bewegen een verbetering in fysieke fitheid oplevert en dat deze verbetering ervoor zorgt dat de executieve functies verbeteren. Fysieke fitheid is het vermogen om fysieke activiteit te kunnen leveren en wordt in dit proefschrift opgedeeld in drie gezondheid gerelateerde componenten: Uithoudingsvermogen, kracht en *Body Mass Index* (BMI). Om deze hypothese te toetsen is, als onderdeel van de studie 'Fit & Vaardig op school', een interventieprogramma ontwikkeld waarbij matig tot intensieve fysieke activiteit wordt geïntegreerd in de taal- en rekenlessen. Tijdens de reken- en taalles zijn de kinderen van groep 4 of groep 5 van 12 basisscholen drie keer per week, gedurende 30 minuten, matig tot intensief aan het bewegen.

Mogelijke voordelen van fysiek actieve taal- en rekenlessen zijn maatschappelijk gezien voornamelijk belangrijk voor kinderen met een lage sociaaleconomische status (SES). Basisschoolleerlingen waarvan de ouders een (zeer) laag opleidingsniveau hebben (achterstandsleerlingen) zijn vaak minder fit en hebben over het algemeen lagere schoolprestaties dan basisschoolleerlingen zonder deze achterstand. Deze academische prestatiekloof ontstaat tijdens de basisschoolperiode, loopt door tijdens de adolescentie en wordt vaak niet meer ingehaald. Dit kan grote sociale en economische gevolgen hebben voor het kind. In de studies beschreven in de eerste twee hoofdstukken van dit proefschrift is eerst onderzocht of achterstandsleerlingen lager scoren op fysieke fitheid, executieve functies en schoolprestaties dan leerlingen zonder deze achterstand. In hoofdstuk 3 en 4 zijn studies beschreven waarin de effecten zijn onderzocht van de fysiek actieve taal- en rekenlessen op fysieke fitheid en executieve functies.

Hoofdstuk 2 beschrijft een cross-sectionele studie waarin is onderzocht of er een verband is tussen SES (vastgesteld op basis van opleidingsniveau van de ouders) en schoolprestaties, tussen SES en fysieke fitheid en tussen fysieke fitheid en schoolprestaties. De resultaten laten zien dat achterstandsleerlingen significant lager scoren op reken-, spelling- en leesvaardigheid vergeleken met kinderen zonder achterstand, maar dat ze geen lagere fysieke fitheid hebben. Ook is er aangetoond dat uithoudingsvermogen is gerelateerd aan rekenvaardigheid. Uithoudingsvermogen is ook gerelateerd aan spelling, maar alleen voor kinderen zonder achterstand. Fysieke fitheid is niet gerelateerd aan leesvaardigheid.

Hoofdstuk 3 beschrijft een cross-sectionele studie waarin het verband tussen SES en executieve functies is onderzocht en of dit verband samenhangt met fysieke fitheid. Uit deze studie blijkt dat achterstandsleerlingen lager scoren dan leerlingen zonder achterstand op één van de drie onderdelen van executieve functies, namelijk cognitieve flexibiliteit. Achterstandsleerlingen scoren niet lager dan kinderen zonder achterstand of hoger op inhibitie of werkgeheugen. Daarnaast is aangetoond dat uithoudingsvermogen is gerelateerd aan cognitieve flexibiliteit. Met deze bevindingen kan geen causaliteit worden aangetoond, maar het verbeteren van uithoudingsvermogen bij zowel achterstandsleerlingen als leerlingen zonder achterstand zou een verbetering van rekenvaardigheid en cognitieve flexibiliteit kunnen opleveren.

Om de executieve functies en schoolprestaties te verbeteren hebben we een 2-jarig interventieprogramma ontwikkeld en uitgevoerd waarbij fysieke activiteit werd geïntegreerd in de reguliere taal- en rekenlessen (‘Fit en Vaardig op school’). Deze lessen werden 3 keer per week in het klaslokaal gegeven, met een totale duur van 22 weken per jaar. Elke les bestond uit 10-15 minuten rekenen, gevolgd door 10-15 minuten taal. Op het digitale schoolbord werden de taal- en rekenopdrachten samen met de fysieke oefeningen zichtbaar gemaakt. Zo moesten de kinderen bijvoorbeeld een woord spellen door een sprong te maken bij elke uitgesproken letter of moesten ze antwoord geven op een rekensom door het juiste aantal keer een wisselsprong uit te voeren. De nadruk van de lessen lag op het automatiseren en herhalen van de lesstof. **Hoofdstuk 4 en 5** beschrijft de cluster-gerandomiseerde studies waarin de effecten van deze lessen op BMI, fysieke fitheid en executieve functies zijn onderzocht. Hieruit blijkt dat kinderen die deelnemen aan het interventieprogramma niet significant meer vooruit gaan op uithoudingsvermogen of kracht dan kinderen die dit programma niet volgen. Daarnaast blijkt dat na 1 jaar de BMI van de kinderen in groep 5 die het interventieprogramma niet volgen significant omhoog gaat, terwijl de BMI van de kinderen in groep 5 die het interventieprogramma wel volgen gelijk blijft (hoe hoger de BMI, hoe groter de kans op overgewicht en obesitas wordt). De kinderen in groep 5 die het interventieprogramma volgen hebben dus een lagere kans op overgewicht en obesitas. Na 2 interventiejaren blijkt dat kinderen die het interventieprogramma volgen meer vooruitgaan op snelheid/wendbaarheid, maar minder vooruit gaan op statische kracht dan de kinderen die het interventieprogramma niet volgen. Er zijn geen verschillen gevonden voor executieve functies.

Onderzoek naar fysiek actieve taal- en rekenlessen staat nog in de kinderschoenen, maar het huidige proefschrift laat zien dat fysieke activiteit kan worden geïmplementeerd in het taal- en rekenonderwijs. Concluderend kan gesteld worden dat achterstandsleerlingen niet minder fit zijn dan kinderen zonder deze achterstand. Daarnaast hebben de fysiek actieve taal- en rekenlessen met de huidige intensiteit en frequentie weinig effecten opgeleverd voor wat betreft de fysieke fitheid en executieve functies. Recentelijk onderzoek laat zien dat het verbeteren van fysieke fitheid niet noodzakelijk is voor het verbeteren van executieve functies bij basisschoolkinderen. Bovendien is het mogelijk dat cognitief uitdagende fysieke activiteit wellicht meer effect oplevert op executieve functies dan fysieke activiteit gericht op het verbeteren van fysieke fitheid. Vervolgonderzoek zou zich daarom kunnen richten op het vergelijken van fysieke activiteiten met een verschillende mate van cognitieve uitdaging.

DANKWOORD

De afgelopen jaren heb ik met veel plezier aan de studie 'Fit en Vaardig op school' gewerkt. Dit heeft uiteindelijk geresulteerd in het huidige proefschrift. Een onderzoek uitvoeren op 18 verschillende basisscholen is geen makkelijke taak, maar ik heb mogen werken in een fantastisch team met heel veel mensen die bereid zijn geweest om de studie succesvol af te ronden. Op de resultaten van de studie ben ik enorm trots en ik ben iedereen, die op wat voor manier dan ook heeft bijgedragen aan de totstandkoming van dit proefschrift, enorm dankbaar. Ik wil via deze weg nogmaals een aantal mensen persoonlijk benoemen.

Allereerst dr. Esther Hartman, mijn co-promotor. Beste Esther, de rust, enthousiasme en het geduld die je uitstraalt is fantastisch. Radio, televisie, directeuren, ouders, leerkrachten, studenten…Hoe regel je dat allemaal zonder dat het schrijftijd kost?! Jij wist het antwoord ook niet altijd, maar we kwamen er altijd uit. Ik regel graag veel dingen zelf (dat moet ik nog steeds afleren), maar als ik hulp of feedback nodig had of gewoon iemand om mee te sparren dan was er altijd wel een moment waarop ik kon langskomen. Bedankt!

Beste Marijke Mullender-Wijnsma, mijn PhD-collega in het onderzoek 'Fit & Vaardig op school'. Ik heb nog nooit zo intens en lang moeten samenwerken met een collega. Iemand van wie je enorm afhankelijk bent voor het slagen van het onderzoek. Dit is spannend, maar ik ben heel erg blij met de manier waarop we hier uit zijn gekomen. Het moment dat ik bij je thuis kwam, je man en kinderen kon ontmoeten, toen heb ik je pas echt leren kennen. Je focus en je doorzettingsvermogen is enorm en ik heb veel van je kunnen leren. Je bent fantastisch om mee samen te werken.

Beste prof. dr. Chris Visscher, mijn promotor. Jij hield de grote lijnen in de gaten en daagde mij steeds uit om daar ook beter over na te denken. Jij hebt er ook voor gezorgd dat het gehele 'Fit en Vaardig'-team kon blijven samenwerken. Als iedereen in het team wordt uitgedaagd en zijn limieten moet opzoeken om het onderzoek af te ronden, wordt het spannend. Gelukkig wist jij dan de juiste sturing te geven. Daar heb je veel ervaring en mensenkennis voor nodig en ik ben enorm dankbaar dat jij die kwaliteiten bezit en inzet op het juiste moment.

Beste prof. dr. Roel Bosker, mijn promotor. Wat is het fijn om jou er bij te hebben. Je kennis over de statistiek is enorm waardevol. Daarnaast is het fantastisch om iemand erbij te hebben die knopen durft door te hakken. dr. Simone Doolaard, mijn co-promotor. Je weet vaak toch net even die cruciale fouten in mijn artikel aan te wijzen en je ervaring in het onderzoek doen op basisscholen heeft er voor gezorgd dat wij voorbereid naar de scholen konden stappen. Heel fijn! Beste dr. Anneke van der Niet, mijn collega en kamergenoot. Je georganiseerde manier van werken (de perfecte rechte stapels papier), je focus, je lef en hoe jij om kan gaan met mensen… ik heb enorm veel van je mogen leren de afgelopen 4 jaar. Ik kon niet veel voor je terug doen, jij redt je altijd wel. Toch enorm bedankt voor al je advies en ik mis onze 'uit-het-raam-staar'-momenten wel een beetje.

Ik wil alle studenten, testleiders, interventieleerkrachten, directeuren, leerkrachten en de kinderen die mee hebben gedaan aan het onderzoek enorm bedanken voor jullie inzet en gezelligheid. In het bijzonder wil ik Grietje en Lidewij bedanken. Jullie waren de eerste leerkrachten die met de lessen aan de slag zijn gegaan en wat hebben jullie dit fantastisch gedaan. Niks was te veel gevraagd en jullie stonden altijd klaar om te helpen, heel fijn. Daarnaast wil ik ook Manon, meester Bas, Anneke en Sanne bedanken. Jullie waren voor alle taken in te zetten, de samenwerking ging altijd vlekkeloos en jullie deden dit met enorm veel enthousiasme. Bedankt!

Ook mijn collega's van BW wil ik bedanken. Het waren misschien wat gekke tijden en plaatsen waar we ons werkoverleg hadden gepland: de Toeter, Ischgl, Bulls, Flachau, Uurwerker, langs de snelweg naast een vrachtwagen, de Twister, langs de lijn bij Heerenveen, op de ijsbaan, tijdens de fietsroute van de Elfstedentocht en tijdens het wachten bij de plaatsnaambordjes van de Noorderrondrit; maar wat ben ik blij dat ik deze momenten met jullie heb mogen meemaken. Ik moet de laatste tijd wat vaker afhaken, maar ik heb enorm genoten van onze fantastische momenten. Daarnaast wil ik de mensen van de technische ondersteuning, Wim, Emyl, Henry en Dirk bedanken voor het regelen van het materiaal; Martine en Geesje voor de financiële afhandeling; en de mensen van het secretariaat, Dea, Wia en Netty voor o.a. het bestellen van de 20.000 enveloppen en de gezellige koffiepraat.

Tijdens het project zijn er zoveel mensen geweest die op een of andere voor manier een bijdrage hebben geleverd, dat ik niet iedereen persoonlijk kan bedanken, maar als laatste wil ik Eeke Scheweer bedanken. Heel fijn dat ik altijd terecht kon voor een inhoudelijk of persoonlijk gesprek. Tijdens deze gesprekken heb ik veel over het werken in teamverband en over het marckisme mogen leren. Fantastisch!

Marck.

ABOUT THE AUTHOR

Marck de Greeff was born on April 3rd 1986 in Voorst, the Netherlands. After graduating secondary school in 2004 at the Etty Hillesum Lyceum in Deventer, he started his study Human Movement Sciences at the University of Groningen with an interest in exercise and sport. During his study he was actively involved in the student community, as a member of almanac committee and a student mentor. He conducted his master thesis as an intern at the Royal Dutch Speed Skating Federation (KSNB). In 2010 he received his master's degree for his work about talent development in talented adolescent speed skaters.

After working for 4 months at the Hanze University of Applied Sciences on a research report about the effects of physically active intervention programs in physically disabled patients, Marck started his PhD research in 2011 at the University of Groningen. During his PhD he stayed actively involved in the student community, as a student mentor, as the chair of the organizing committee for the VvBN PhD-day 2014, by reading aloud at a primary school and by giving lectures/presentations/workshops about physically active academic lessons.

Marck is currently working as a researcher within the project "Learning by Moving". In this project we examine the effects of two intervention programs with different cognitive demands (aerobic exercise versus cognitive engaging exercise) on cognitive performance within preadolescent children.

LIST OF PUBLICATIONS

De Greeff, J. W., Hartman, E., Mullender-Wijnsma, M. J., Bosker, R. J., Doolaard, S., & Visscher, C. (2016). Effect of physically active academic lessons on body mass index and physical fitness. Journal of School Health, 86(5), 346-352.

De Greeff, J. W., Hartman, E., Mullender-Wijnsma, M. J., Bosker, R. J., Doolaard, S., & Visscher, C. (2016). Long-term effects of physically active academic lessons on physical fitness and executive functions in primary school children. Health Education Research, 31(2), 185-194.

Mullender-Wijnsma, M. J., Hartman, E., **de Greeff, J. W.**, Doolaard, S., Bosker, R. J., & Visscher, C. (2016). Physically active math and language lessons improve academic achievement: A cluster randomized controlled trial. Pediatrics, 137(3), 1-9.

Mullender-Wijnsma, M. J., Hartman, E., **de Greeff, J. W.**, Bosker, R. J., Doolaard, S., & Visscher, C. (2015a). Improving academic performance of school-age children by physical activity in the classroom: Year one program evaluation. Journal of School Health, 85(6), 365-371.

Mullender-Wijnsma, M. J., Hartman, E., **de Greeff, J. W.**, Bosker, R. J., Doolaard, S., & Visscher, C. (2015b). Moderate-to-vigorous physically active academic lessons and academic engagement in children with and without a social disadvantage: A within subject experimental design. BMC Public Health, 15(1), 404.

De Greeff, J. W., Hartman, E., Mullender-Wijnsma, M. J., Bosker, R. J., Doolaard, S., & Visscher, C. (2014). Physical fitness and academic performance in primary school children with and without a social disadvantage. Health Education Research, 29(5), 853-860.

De Greeff, J.W., Elferink-Gemser, M. T., Sierksma, G., & Visscher, C. (2011). Explaining the performance of talented youth speed skaters. CA-IUC, (1), p. 83-99.

SUBMITTED FOR PUBLICATION

De Greeff, J.W., Hartman, E., Mullender-Wijnsma, M. J., Bosker R.J., Doolaard, S., & Visscher, C. (submitted). The relationship between socioeconomic status and executive functions: Is there a mediating role of physical fitness? Manuscript submitted for publication.

PROCEEDINGS AND OTHERS

De Greeff, J.W., Mullender-Wijnsma, M.J., Hartman, E. & Visscher, C. (2015). Bewegen en leren moet je combineren. Lichamelijke opvoeding, nummer 2, jaargang 103.

De Greeff, J.W. (2015). Effect of physically active academic lessons on physical fitness and academic achievement in primary school children (Poster). Pediatric Work Physiology meeting (PWP), Utrecht, 12 september 2015.

De Greeff, J.W. (2014). Fit & Vaardig op school, effect van fysiek actieve reken- en taallessen. Workshop academische PABO, 21 november 2014.

De Greeff, J.W., Hartman, E., Mullender-Wijnsma, M.J., Visscher, C. (2014). Effect van fysiek actieve reken- en taallessen op fysieke fitheid van basisschoolleerlingen. Dag van het Sportonderzoek, Nijmegen, 30 oktober 2014.

De Greeff, J.W., Hartman, E., Mullender-Wijnsma, M.J., Visscher, C. (2014). Effect of physically active academic lessons on physical fitness of preadolescent children. ECSS: 19th Congress of the European College of Sport Sciences, Amsterdam, 3 juli 2014.

De Greeff, J.W. (2014). Bewegen & leren. Studiedag Medilex onderwijs 'Breinbewust onderwijs', Driebergen-Zeist, 15 mei 2014.

De Greeff, J.W. (2014). Bewegen en leren, hoe werkt dat? ODIOM symposium 'Move (on)', Groningen, 14 mei 2014.

De Greeff, J.W. (2013). Workshop bewegen. Dag van de Leerkracht, Onderwijsdagen gemeente Emmen, Emmen, 15 mei 2013.

De Greeff, J.W. (2013). Association between physical fitness and academic performance for children with and without a social disadvantage. BCN PhD retreat, Odoorn, 15 maart 2013.

De Greeff, J.W., Hartman, E., Visscher, C. (2012). Association between aerobic capacity and academic performance for children with and without a social disadvantage. International congress on enhancement of physical activity and motor skills (ICEPA), Jyväskylä, Finland, 1 November 2012.

De Greeff, J.W. (2012). ENERGIE, waar halen ze 'het' vandaan? Algemene ouderavond, Willem Lodewijk Gymnasium, Groningen, 15 maart 2011.

De Greeff, J.W. (2011). Het effect van bewegen tijdens de reguliere les op de taal-, en rekenvaardigheden van achterstandsleerlingen in groep 4 en 5. Dag van het Sportonderzoek, Amsterdam, p. 34-35.

MEDIA

RTL4. EditieNL. Maandag 4 november 2013. 2 x 5 = 10 keer springen. Reportage en interview met **J.W. de Greeff** naar aanleiding van de eerste resultaten.

Radio 1. De Gids.fm. Dinsdag 3 januari 2012. Interview met **J.W. de Greeff** over 'Bewegend leren werkt beter'.

Webmagazine. UMCG Kennisinzicht. Webmagazine 'in de lift'. Maandag 5 maart 2012. Beter leren door bewegen in de klas. Reportage en interview met **J.W. de Greeff** naar aanleiding van de start van de interventie.

RTV Drenthe. Drenthe Nu. Dinsdag 20 december 2011. Bewegend leren op Drentse scholen. Nieuwsitem over het beweegprogramma op de scholen in combinatie met interview met **J.W. de Greeff**.

RESEARCH INSTITUTE SHARE

This thesis is published within the **Research Institute SHARE** (Science in Healthy Ageing and healthcaRE) of the University Medical Center Groningen / University of Groningen. Further information regarding the institute and its research can be obtained from our internetsite: http://www.share.umcg.nl/.

More recent theses can be found in the list below.
((co-)supervisors are between brackets)

2016

Armbrust W
The impact of juvenile idiopathic arthritis; moving beyond the joint
(prof PJJ Sauer, prof JHB Geertzen, prof NM Wulffraat)

Roy A
The development of depression in children and adolescents with ADHD
(prof AJ Oldehinkel, dr CA Hartman)

Holubcikova J
Eating habits, body image and health and behavioural problems of adolescents; the role of school and family context
(prof SA Reijneveld, dr JP van Dijk, dr A Madarasova-Geckova, dr P Kolarcik)

Nguyen TPL
Health economics of screening for hypertension in Vietnam
(prof MJ Postma, dr CCM Schuilinga-Veninga, dr TBY Nguyen, dr EP Wright)

Mihajlovic J
Health economics of targeted cancer therapies; a comparative analysis for Serbia and the Netherlands
(prof MJ Postma, dr P Pechlivanoglou)

Darvishian M
Real-world influenza vaccine effectiveness; new designs and methods to adjust for confounding and bias
(prof E Hak, prof ER van den Heuvel)

Berm EJJ
Optimizing treatment with psychotropic agents through precision drug therapy; it is not about the mean
(prof B Wilffert, prof E Hak, dr JG Maring)

Fugel H-J
Economics of stratified medicine
(prof MJ Postma, dr M Nuijten, dr K Redekop)

Salavati M
Assessing gross motor function, functional skills, and caregiver assistance in children with cerebral palsy (CP) and cerebral palsy impairment (CPI)
(prof CP van der Schans, prof B Steenbergen, dr A Waninge, dr EAA Rameckers)

Wierike SCM te
'The' pathway towards the elite level in Dutch basketball; a multidimensional and longitudinal study on the development of talented youth basketball players
(prof C Visscher, dr MT Elferink-Gemser)

Jacobs JJWM
General practitioner on an island. How research and innovation help to improve primary care
(prof R Sanderman, prof T van der Molen)

Küpers LK
The first 1000 days and beyond
(prof H Snieder, prof RP Stolk, dr E Corpeleijn)

Kuiper JS
The importance of social relationships in the process of cognitive ageing
(prof RC Oude Voshaar, prof RP Stolk, dr N Smidt)

Göhner, C
Placental particles in pregnancy and preeclampsia
(prof SA Scherjon,prof E Schleuβner, dr MM Faas, dr T Plösch)

Vries AJ de
Patellar tendinopathy; causes, consequences and the use of orthoses
(prof RL Diercks, dr I van den Akker-Scheek, dr J Zwerver, dr H van der Worp)

Holland B van
Promotion of sustainable employment; occupational health in the meat processing industry
(prof MF Reneman, prof S Brouwer, dr R Soer, dr MR de Boer)
13.04.2016 EXPAND

Otter TA
Monitoring endurance athletes; a multidisciplinary approach
(prof KAPM Lemmink, prof RL Diercks, dr MS Brink)

Bielderman JH
Active ageing and quality of life; community-dwelling older adults in deprived neighbourhoods
(prof CP van der Schans, dr MHG de Greef, dr GH Schout)

For more 2016 and earlier theses visit our website.